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- Boyce, J.S.: A Study of Decay in Douglas Fir in the Pacific Northwest. Bul.U.S.D.A. 1163: 1-19. 1923.
- : The Deterioration of Felled Western Yellow Pine on Insect-Control Projects. Bul.U.S.D.A. 1140: 1-7. 1923.
- : Decays and Discolorations in Air-plane Woods. Bul.U.S.D.A. 1128: 1-51. 1923.
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- Hartley, Carl: Damping-off in Forest Nurseries. Bul.U.S.D.A. 934: 1-99. 1921.
- : The Control of Damping-off of Coniferous Seedlings. Bul.U.S.D.A. 453: 1-32. 1917.
- : Injury by Disinfectants to Seeds and Roots in Sandy Soils. Bul.U.S.D.A. 169: 1-35. 1915.
- : The Blights of Coniferous Nursery Stock. Bul.U.S.D.A. 44: 1-21. 1913.
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- Howard, Nathaniel O.: The Control of Sap-stain, Mold, and Incipient Decay in Green Wood with Special Reference to Vehicle Stock. Bul. U.S.D.A. 1037: 1-55. 1922.
- Hubert, Ernest E.: Effect of Kiln Drying, Steaming, and Air Seasoning on Certain Fungi in Wood. Bul.U.S.D.A. 1262: 1-20. 1924.
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THE BLIGHTS OF CONIFEROUS NURSERY STOCK.

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INTRODUCTION.

There has been a good deal of complaint from forest and ornamental nurseries in various parts of the country of injury to conifers by blight. All cases in which trees in the nursery turn brown and die, in whole or in part, without any very definite symptom to indicate what caused death are classed as blight.

The damping-off diseases and those caused by the rust fungi, detailed descriptions of which may be found in a bulletin by Spaulding,¹ are not included under the name "blight." Damping-off attacks only very young seedlings, doing most of its damage during the first three weeks after germination. It is caused by several parasitic fungi which attack the soft tissues of the tender seedlings and rot them, often entirely destroying great numbers of plants in a few days. Unfortunately one of these fungi sometimes continues to kill seedlings for a time after they have become older and tougher, so that they look more as if they had been killed by a blight than by damping-off.

Because of the difficulty in finding a natural dividing line between the damping-off diseases and the blights, it has become necessary to draw an arbitrary line between them. All parasitic death of seedlings less than 2 months old will be classed as damping-off. The reason for this classification will be presented under the heading "Root-rots." The present paper will consider as blights only diseases of stock more than 2 months old. Since the rust fungi are not common in our nurseries and make their presence known before the death of the plant by swellings of the stems and by the breaking out of orange-colored spore pustules, there should be no difficulty in dis-

¹ Spaulding, Perley. The blister rust of white pine. U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 206, 88 p., 2 pl., 5 fig., 1911.

tinguishing between blights on the one hand and damping-off and rusts on the other.

Losses caused by blight are very considerable, nurseries not infrequently losing practically their entire stock of one or more species of conifers by blight attacks. In many of these cases both the cause of the attack and methods of preventing or stopping it have been entirely unknown. No systematic investigation of these blight attacks had been undertaken in this country. In studying the problem the writer since 1909 has visited 31 nurseries which raise conifers and has corresponded with many others. Many different types of blight have been found to exist. By his own observation and experimental work and by bringing together the information obtained from practical nurserymen and from the European literature on nursery diseases, the writer has succeeded in distinguishing quite clearly between the most important types of blight and drawing conclusions as to the best preventive measures. In the following pages the causes, distinguishing characters, and preventive measures for all of the types of blight met with are given as fully as the present condition of our knowledge will permit.

PHYSIOLOGICAL TROUBLES.

SUN SCORCH.

Sun scorch is the commonest and most serious trouble in most of the nurseries. By sun scorch is meant the death of entire seedlings or transplants or parts of them, due to lack of balance between the water absorption by the roots and water loss from the needles during the growing season. Stated in a somewhat simpler way, sun scorch is drought injury which occurs in the growing season. The term "sun scorch" has been used by Stone¹ and others for a similar trouble of conifers in New England forests. Its work in second-year seed beds on sandy soil has been described by Hartig.² It will be considered in detail, because in many cases it resembles other diseases so closely as to go unrecognized. For example, sun scorch for several years caused heavy losses in both seedlings and transplants at the Forest Service nursery at Halsey, Nebr., where most of the writer's work on this disease has been done. In a single case the records indicated a loss of 70 per cent of all the 2-year-old seedlings of jack pine (*Pinus divaricata* (Ait.) Gordon) and Scotch pine (*P. sylvestris* L.). The damage looked so little like drought that for some time it was supposed to be due to parasitic fungi, and Bordeaux mixture was employed to control it. Losses from this disease have

¹ Stone, G. E. Sun scorch of the pine. Massachusetts Agricultural Experiment Station, 22d Annual Report, pt. 2 [1909], p. 65-69, 1910.

² Hartig, Robert. Lehrbuch der Baumkrankheiten. Aufl. 2, Berlin, 1889, p. 104.

occurred at nurseries in Colorado, Minnesota, Pennsylvania, and New York without being recognized by the nurserymen.

HOW SUN SCORCH WORKS.

In serious cases of sun scorch, seedlings of all ages are killed outright. In less serious cases part of the plant is killed. Either the tips or the lower needles may be first affected. If the tips are injured, stem and bud may be killed as well as the needles, so that growth can be resumed only by lateral buds below the point of injury. In slight attacks only the needles, and often only the tips of the needles, are killed. When the lower needles are the only ones attacked, despite the fact that they are well protected from sun and wind in dense stands, it must be assumed that the younger needles at the tips, subjected to much more light and wind, have survived at the expense of the lower ones by taking more than their share of the available water. Affected needles first turn slightly yellowish, lose their green until they have become a pale straw color, and then gradually turn deeper brown until they become nearly red. In summer most dead needles fall within a month.

In crowded seed beds, especially on very sandy soil, attacks may take place very suddenly in hot, dry weather, and patches of seedlings up to a foot in diameter may be entirely killed. It is these definite, clean-killed patches which have most often caused the disease to be called parasitic. Such even death can be explained on a drought basis only by assuming that in such cases the root systems of all the seedlings involved have been equally extended in normal competition for water, just as the tops often grow to an exactly even height in competition for light, so that all the seedlings in the patch are on terms of equality when the competition becomes critical. When part of the seedlings in a crowded bed are badly suppressed the smaller seedlings are in some cases, when transpiration is rapid, even less subject to sun scorch than the larger. Since the suppressed seedlings presumably have less extensive root systems, their endurance in such cases must be explained by the fact that they are also less subject to water loss because of the protection afforded by the tops of the larger plants around them. When the beds are not crowded and the weather does not favor extremely rapid water loss, death does not occur so suddenly or in such definite patches.

In the cases of transplants a certain number die soon after they are set out and before root growth starts. This has been called "transplanting loss" and is not included under the term "sun scorch." "Sun scorch" is used in transplants for death due to excessive water loss after the plants have become partly established and commenced growth. The work of sun scorch in transplant beds at Halsey differs from that in seed beds in that the trouble in the transplants does not

occur in such distinct patches; and if any part of a transplant is affected, either an entire branch or the entire plant dies at once.

A feature of sun scorch in nurseries, as well as in the older trees described by Stone,¹ is that the absorbing portions of roots die at the same time as the tops or even before. This indicates that the leaf and stem tissues can stand water loss better than the vegetative tissues of the roots. Especially in the case of transplants the cambium of the entire root system, or at least of the outlying portions of it, has been found to be dead and brown. By the time the needles show the first signs of yellowing, a large part of the root cambium is already gone. This especially early death of a large proportion of the root systems of the scorched transplants is probably due to the fact that a tree in the transplant bed has a smaller root system in proportion to its transpiring surface than a second-year seedling would have. When only a part of the needles on a plant are killed it appears that the damage to the root is more extensive than to the tops. This is indicated by the fact that a plant which has lost part of its needles in an attack of this disease is more likely to succumb to later attacks of the same nature. Evidently the reduction in transpiring surface caused by the first attack is more than counterbalanced by the reduction in absorbing surface.

During several sun-scorch attacks at Halsey, and at two or three other times when the weather was hot and dry but no actual sun scorch had occurred, a peculiar type of injury appeared on young, growing shoots of second-year pine seedlings. White, shrunken, watery-looking patches appeared on the green stems rather suddenly, followed by the death of the plant beyond the point attacked. A very similar "white-spot" injury, occurring near the bases of the stems of seedlings less than a month old at the Halsey nursery, and which has often been confused with damping-off, can be controlled by shading and watering. While a parasite may be in some way concerned in causing the trouble in both ages of stock, there is little doubt that drought and possibly also excessive light or heat working independently are mainly responsible. This white-spot injury to second-year seedlings is included under sun scorch because it often occurs simultaneously and can be prevented by the measures which prevent scorch. It is not important.

EVIDENCE AS TO CAUSE OF SUN SCORCH.

The conclusion that the disease is due to disproportionate water loss is based on the following facts:

(1) Spraying with fungicides has failed to control the trouble. While spraying experiments have not been exhaustive, Bordeaux

¹ Stone, G. E. Sun scorch of the pine. Massachusetts Agricultural Experiment Station, 22d Annual Report, pt. 2 [1909], p. 65-69, 1910.

mixture, ammoniacal copper carbonate, and copper acetate were tested repeatedly during several seasons. Unfortunately for the experiments, little trouble with the disease occurred at the times when the fungicides were used. In four cases, however, the disease attacked parts of the nursery containing experimental plats which had been more or less recently sprayed with copper mixtures containing soap. In these cases there was no evidence that the fungicides afforded any protection. This lessens the likelihood that needle parasites are concerned in causing the disease.

(2) On sandy soil the attacks which most closely imitate parasitic injury by killing definite patches occur suddenly and often simultaneously in many parts of the nursery. Serious damage may appear through thousands of square feet of seed beds inside of 48 hours from the time the first evidence occurs. This renders it unlikely that root parasites play any important part in causing the disease.

(3) The most typical attacks of the disease observed at Halsey occurred on days when wind and temperature were high and humidity low and following nights which had been unusually warm and without dew—conditions which favor excessive transpiration. This emphasizes the relation of transpiration to the disease.

(4) In general, the most trouble occurs during dry seasons. The larger commercial nurseries in Minnesota and Iowa report that the most serious trouble they have had was during the very unusually dry summer of 1910.

(5) Partial shade greatly decreases loss and entirely prevents trouble except in very severe attacks or during persistent drought. Shade was tested in five different attacks at Halsey in 1908, 1909, and 1910, and in all cases controlled or greatly lessened the losses, as indicated by the results in adjacent shaded and unshaded plats.

(6) Crowding strongly predisposes to the trouble. In the beds at Halsey the seedlings at the margins which have sent their roots out into the unoccupied paths are practically never attacked, though in some cases the entire interiors of beds have been killed. This immunity of the edges of the beds is more marked on sandy soils than on heavier ones.

(7) Attacks of the disease regularly occur when the soil is very dry. Very sandy soils, which are more quickly reduced to a low water content, are the commonest locations for the disease. In two different attacks at Halsey direct comparisons were made of soil moisture in diseased and relatively healthy areas, taking samples between the depths of 7 and 11 inches, where the greatest mass of absorbing roots lay. In one case the samples from the four points tested in the healthy area showed an average water content 32 per cent higher than that of the two points taken in the blighted stand adjacent. At the time of the other attack four samples were taken

from the blighted area and two from the healthy, and determination showed 30 per cent more water in the samples from the healthy area. Altogether, samples taken at 10 different points in diseased stands during three different attacks gave an average moisture content of 3.4 per cent for the soil from 2 to 11 inches in depth. The average wilting coefficient of the soil at this nursery, determined from samples taken from the same depths at nine different points located in the same parts of the nursery as the moisture determinations above referred to, was 3.6 per cent, as determined by the indirect method of Briggs and Shantz from moisture-equivalent determinations made by the Laboratory of Biophysical Investigations. While the soil-moisture determinations made were too few to establish the relation of dry soil to the disease, they are to be viewed as contributory evidence.

(8) High points in beds and the centers of arched beds from which the water runs off or which are missed in flood irrigation are especially liable to damage from the disease.

(9) Species which normally inhabit moist soil suffer most. Norway spruce (*Picea excelsa* Link) and Douglas fir (*Pseudotsuga taxifolia* (Poir.) Britt.) seem to suffer oftener than the pines. Western yellow pine (*Pinus ponderosa* Lawson) grown from Rocky Mountain seed is more resistant at Halsey than other pines.

(10) Sufficiently frequent and heavy watering will entirely prevent the disease. In three different attacks at Halsey evidence of the preventive effect of watering was obtained. The main practical fact is that for two seasons the nurserymen at Halsey and at Monument, Colo., have practically controlled the disease by increasing the frequency of watering. At these nurseries during the three preceding seasons the disease had caused considerable loss. At both these nurseries the disease had been considered parasitic.

It is not thought that death is usually due to the entire lack of available soil moisture. It is rather probable that it usually occurs when there is still a certain amount of available water left in some part of the soil reached by the root system, but so small in quantity that it can not be taken up by the roots fast enough to supply the demands of the rapid transpiration loss from the needles. This does not necessarily mean slowness of imbibition; it may simply mean that the capillary water movement from outlying soil particles to the particles adjoining the root surface is too slow when the soil is nearly dry. That this is the case is indicated by the fact that after an attack of sun scorch has started as the result of one or two days of rapid transpiration, when the soil is quite dry, the disease may stop spreading on the advent of cooler weather without the addition of any water to the soil from above.

Some interesting occurrences at Halsey in connection with this trouble, which at first appeared to contradict the relation of the dis-

ease to water loss, may be mentioned. Losses have frequently been more serious in the nursery transplant beds than in the trees planted out in the sand hills, where there is little humus and no wind protection and where no artificial watering is done. This was advanced as an argument against drought as a cause of the trouble. The fallacies in this argument are that the trees used in the hills had been previously once transplanted, so that they were stronger and better rooted stock, and that in the hill plantations there was not so much competition as in the transplant beds, where the close stands of trees exhaust soil moisture very rapidly.

Another argument against drought as a cause of the disease was the fact that in certain cases the blight appeared at Halsey when the soil 2 or 3 inches down seemed quite moist. However, further examination and quantitative determinations of moisture content showed that at such times the soil around the mass of absorbing roots is drier than the soil near the surface. The dense stands of seedlings apparently exhaust the soil moisture at the lower levels more rapidly than evaporation takes the water nearer the surface.

A further argument advanced against the drought theory is the fact that at Halsey trouble often occurs within a very few days after fairly heavy rains. This happens, however, only in very drying weather and in beds where the stand is dense. Under such conditions the moisture is drawn from the sandy soil very rapidly, so that in all such cases the soil around the roots is found to be very dry despite relatively recent rains.

One case of sun scorch occurred at Halsey in 1910 which was quite difficult to explain, although the evidence presented by adjacent plats, some of which had been shaded and some especially watered, left little doubt as to its relation to drought. On July 25 and 26 a period of hot weather culminated in temperatures of 100° and 96° F., respectively. At about 7 a. m. July 27, 0.28 inch of rain fell. The sky cleared immediately after, the temperature rose to 102°, and the air became dry. July 28 was cool and cloudy. On that morning a large number of the smallest grade of 2-year-old jack-pine transplants had begun to turn yellow, and in 24 hours about one-third of all the stock of this class showed injury. Trees continued to turn yellow and die in decreasing numbers during three or four days of cool, partly cloudy weather following till the loss reached fully 50 per cent. The 0.28 inch rain of the 27th appeared to penetrate to the roots through the rather coarse soil. The best explanation seems to be that the roots were injured by the excessive demand on them during July 25 and 26, before the rain fell, or on July 27, before the rain had time to get down to the root level. The failure of the tops to show injury till some time after the roots are hurt is always more marked in transplants than in seedlings. There seems to be no rea-

son to think that the high temperature of July 27 injured the trees directly. While 102° F. is unusually high, the temperature has gone to 107° at this nursery without injury to the pines.

The death of the roots, especially characteristic of sun scorch in transplants, has led to the belief in some quarters that root parasites were the immediate cause of the disease. The evidence obtained contradicts this view. The most that can be said is that in many places some of the common soil fungi may act as facultative parasites, killing weakened portions of root systems and so making the plants somewhat less able to withstand drought injury. Even this has not been demonstrated, and from the nature of the case it is practically impossible to demonstrate it. An attempt was made to secure evidence on this point by carefully washing the roots of healthy 1-year-old jack-pine seedlings and planting part in autoclaved soil and part in untreated soil. All the soil used came from part of a bed at the Halsey nursery which had been affected with sun scorch. After the plants had had a few weeks to become established all the pots were allowed to dry out. Death occurred in a manner fairly characteristic of sun scorch, coming at practically the same time in both sterilized and unsterilized pots. Microscopic examination indicated about the same fungi in the dead roots in both sterilized and unsterilized soil. The results were entirely negative. Because of the impossibility of securing a growth of stock large enough to exhibit typical blight symptoms and of keeping any of it free enough from common soil organisms to use as controls for inoculation tests, there is little chance of learning anything definite as to what part fungi may play in causing sun scorch.

Taken as a whole, the evidence is believed sufficient to establish a lack of balance between water absorption and water loss as the chief, if not the only, cause of the disease. While there have at times been occurrences rather difficult to explain, 13 different attacks of the disease have been seen at Halsey, and in all of them evidence has been obtained of the relation of the trouble to drying weather, shade, crowding, or soil moisture, and in most cases to two or more of these factors. The Halsey nursery has been under fairly continuous observation by the writer during the summers of 1909, 1910, 1911, and 1912, and it can be said quite positively that all the serious losses which occurred in established stock over 1 year old during the growing seasons in this period could have been averted by maintaining sufficient soil moisture and mostly averted by shading. While the conditions are in many ways different from those at other nurseries, the evidence here obtained has been checked up by observations made at many other nurseries from the Rocky Mountains to the Atlantic coast. While some of the other diseases listed in this paper undoubtedly are concerned in the spring and summer losses at many

of the nurseries, the writer is confident that the largest proportion of the damage to pine, spruce, and fir nursery stock during the growing season can be classed as sun scorch.

HOW TO RECOGNIZE SUN SCORCH.

The best way to tell whether or not an attack of blight is due to sun scorch is to note the relation between the occurrence of the disease and crowding, shading, drying weather, sandiness of soil, lack of soil moisture, and drought resistance of different species, as described in the foregoing paragraphs. The only characteristic of value shown by individual diseased plants is the simultaneous death of needles and root tissue. When the character of the trouble is still in doubt, final determination must rest with the nurseryman. The best method of doing this is to lay out small plats in the beds at different points in the nursery, giving some of them special shade and others regular, heavy watering. If at the next attack of blight these treated plats come out much better than the other beds near them, he can know that the trouble is sun scorch and treat it accordingly.

PREVENTIVE MEASURES.

The best and only absolutely certain way to prevent sun scorch is to water the nursery beds. When stock over two months old is watered it should be watered heavily. The great trouble with artificial watering is that it is usually not done thoroughly. Most of the water applied in sprinkling with the hose, as it is often done, evaporates from the surface without reaching the roots at all, so that even frequent sprinkling is of little value. At Halsey very crowded beds must be heavily watered oftener than once a week in the most drying weather to prevent all injury from sun scorch. With one exception there is no other nursery known to the writer where so much watering is necessary. The density of the stand and the character of the soil and climate must determine the amount of watering needed to prevent trouble. In some nurseries on rather heavy soil no preventive is necessary except in most exceptional drought years.

Objection has been made to much watering, on the ground that it can be expected to make stock less hardy and less able to survive transplanting. Observation of the work of the disease has suggested that the other extreme may also decrease hardiness. If the trees are allowed to become too dry, many which are not killed entirely and which may show little or no damage above ground appear to have enough of their root systems killed to decrease their chance for survival.

At the nursery at Halsey, Nebr., the beds are flooded with water obtained by a lift of a few feet from a river. At Monument, Colo.,

the beds are watered by large portable sprinklers fed from a mountain reservoir. Even with such excellent equipment much watering is expensive. Most of the commercial nurseries have very crude watering facilities and many of them none at all. At many nurseries putting in a watering system simply to prevent sun scorch would not pay. Indirect methods of controlling the disease are therefore of interest.

Shade frames of 2-inch slats, half an inch thick and spaced 2 inches apart, have proved a cheap and quite effective method of controlling the trouble at Halsey, though they do not prevent all loss. This slat shade was tested on July 26, 1910, at noon and at 4.20 p. m., with a photometer using "printing-out" paper. An average of eight determinations indicated that the shaded beds received 42 per cent of the amount of light received by unshaded beds at the same times of day. While this proportion must vary with the angle of the sun's rays, the average figure obtained is considered fairly representative for the period of most rapid transpiration. Therefore, the term "half shade," regularly used for this type of shade, while the best available, is not entirely accurate. When frames are only a foot above the ground, the slats should be placed north and south in order that all parts of the bed may get a reasonably uniform amount of shade. Shade put on after the attack has gone far enough to become noticeable can not prevent all injury, but may decrease it. In the cases of the successful use of shade seen by the writer the shades had been put on several weeks before the attack took place. Brush supported by rough frames 6 feet high is much used over all ages of seedlings by western commercial nurserymen and probably explains much of their relative freedom from sun scorch. Shade presumably keeps the beds from getting as dry as they otherwise would and at the same time enables the plants to live in drier soil than they otherwise could, by reducing the rate of transpiration loss from the needles. In growing stock for western forest planting, where it is difficult to secure survival, there appears the theoretical objection that shade in the nursery beds will make the stock more tender and harder to transplant successfully. Bates and Pierce¹ state that the half shade used at Halsey when kept over second-year seed beds has resulted in greater loss in the transplant beds the following year. They suggest gradually reducing the amount of shade on second-year seed beds. In the case of transplant beds it may be best to use the method tested in 1910 by Mr. C. R. Bechtle, formerly of the Forest Service. He erected rough temporary shade frames over the beds immediately after transplanting and removed them some weeks later when the trees had become partly

¹ Bates, C. G., and Pierce, R. G. Forestation of the sand hills of Nebraska and Kansas. U. S. Department of Agriculture, Forest Service, Bulletin 121, p. 32, 1913.

established. This method tends to protect the transplants during the period when they have the least absorbing root surface and exposes them to the sun during the larger part of the growing period, so that by the end of the season the trees should be thoroughly hardened and ready to stand field planting. Shade will always be a useful adjunct in preventing sun scorch, though the extent to which it should be used will vary greatly with different nurseries.

Crowding should be avoided in order to avoid sun scorch. What constitutes crowding varies greatly at different nurseries and with different species. At Halsey a second-year seed bed containing 75 Scotch pine per square foot is crowded. At Monument 150 Douglas fir per square foot do not crowd each other seriously at the same age. Transplants should be given much more room than seedlings. The older commercial nurseries often practice thinning in their older seed beds and generally give their transplants a great deal of space. Because of the extra cost of weeding and cultivating large areas and the limited space at some nurseries, it is sometimes probably cheaper to crowd stock in a small space and prevent scorch by increased shade or watering.

Extremely sandy soils should be avoided, and any deficiency in humus should be counteracted by manure and soiling crops, so as to increase the water-holding power of the soil. Nurseries on very sandy soils in the Northeastern States appear to have more trouble from sun scorch than western nurseries, which have drier climate but somewhat heavier soil. Windbreaks and surface cultivation are also undoubtedly helpful in preventing sun scorch.

WINTERKILLING.

Winterkilling is generally understood to mean death as a result of drying when the soil and roots are so frozen that the amount of water given off from the leaves can not be replaced to a sufficient extent by absorption from the soil. In this way its cause is fundamentally the same as that of sun scorch, the difference being that it occurs while the soil is frozen. Alternate freezing and thawing is considered important in bringing about damage. This may be due simply to the increased loss of water from the needles during warm periods which do not last long enough to thaw out the soil materially. In the West, the warm winds known as "chinooks" produce such sudden very warm periods in the midst of the coldest weather that not only small plants but even the largest forest trees are sometimes killed.¹

¹ Hedgcock, G. G. Notes on some diseases of trees in our national forests. III. Phytopathology, v. 3, No. 2, p. 112-113, 1913.

Hartley, Carl. Notes on winterkilling of forest trees. Forest Club Annual [University of Nebraska], v. 4, p. 41-46, 1912.

The formation of ice crystals in the younger tissues at the close of the thaws may also be concerned in causing injury. Trees affected by winterkilling in the nursery look much like trees affected with sun scorch. Winterkilling can be distinguished from other types of blight by paying attention to attendant circumstances. The most damage may be looked for during the hardest winters or winters with little snow. It is likely to be worst where the beds are least protected by windbreaks or a mulch and in the least resistant species.

Winterkilling and sun scorch work differently in that winterkilling is worst in open stands, while with sun scorch the case is reversed. This may be explained not only on the ground that the closely sown trees protect each other from drying winds, but also, as pointed out by Forest Supervisor Elers Koch, act as a mulch, protecting the soil from deep freezing.

The ordinary measures for preventing winterkilling are to protect the nursery beds as thoroughly as possible by windbreaks and to mulch the beds with straw. Mulching must be done cautiously. It is likely, especially if heavy or close, to result in mulch injury and do more harm than good. Mulch injury is entirely different from winterkilling and will be considered later in this paper.

Heaving is also distinct from ordinary winterkilling. The roots of nursery stock in heavy soil are sometimes lifted partly or entirely out of the ground by the action of alternate freezing and thawing. Both plants and surface soil are raised by the expansion of the soil in freezing. In thawing, the soil settles back gradually around the roots, which are left higher than they were previously. The process is entirely mechanical. Like winterkilling, heaving can be prevented by mulch.

FROST INJURY.

Frost injury differs from winterkilling in that it is due to the formation of ice crystals in unripened tissue, while winterkilling is probably due mainly to drying out, as above described. In addition to injury to unripened tissue above ground by early frosts, it is possible that early freezing of the soil injures by killing roots which have not yet stopped growth. According to Hartig,¹ trees with injured roots are likely to start growth the following spring before showing any effects and then turn brown rather suddenly. Very late spring seed sowing and encouraging the growth of stock toward the end of the season should be avoided, in order to get the tissues properly ripened up and able to endure freezing. Covering beds with a mulch before the first heavy freeze should prevent injury, though very early mulching must be avoided.

¹ Hartig, Robert. Text-book of the Diseases of Trees. Translated by William Somerville, revised and edited by H. M. Ward. London, 1894, p. 289.

Death from late frosts in the spring is rather frequent. Jack pine, because of its tendency to start growth very early in the spring, frequently loses its terminal buds and young shoots as the result of severe frosts after growth has begun, although these young, tender shoots are capable of standing a temperature considerably below freezing without injury. Douglas fir nursery stock in the West also seems to be quite susceptible to such injury. The use of some form of shade to delay very early growth, placing beds of susceptible species on high ground, and possibly the use of smudges, heaters, or a temporary straw or burlap mulch on nights when frost is feared, are methods which might be suggested for preventing spring frost injury.

EBERMAYER'S BLIGHT.

In Germany, Ebermayer¹ states that death in pine nurseries results from sudden warm weather in early spring when the soil is so cold that the roots are unable to absorb water normally and make good the transpiration loss. The process which he described differs from sun scorch in that it occurs oftenest on heavy soil and when the soil contains excessive moisture. It differs from winterkilling in that it occurs after the soil thaws. He states that the best method of prevention is to decrease the transpiration loss by means of shade in the early spring. This blight does not occur commonly in the United States.

DISEASES DUE TO PARASITIC FUNGI.

NEEDLE-CAST.

Lophodermium pinastri (Schräd.) Chev. causes the shedding or "cast" of pine needles in German nurseries and plantations. The disease is not known to occur in American nurseries, whatever may be the case as to the presence of a fungus, but it is nearly certain to make trouble in the future in moist localities. A brief account of the disease, compiled from various statements of the great number of European writers on the subject, will therefore be given.

The disease has been known in Germany for more than a century under the name of "schütte." The causal relation of the parasite was first reported in 1852,² but was not established till some years later. When the parasitism of the fungus was established some writers apparently accepted it as the only cause of blight, while others, notably Ebermayer, who regarded physical factors as the com-

¹ Ebermayer, Ernst. Die Physikalischen Einwirkungen des Waldes auf Luft und Boden. Bd. 1, Berlin, 1873, p. 251-261.

Zur Schüttekrankheit der Kiefer. Allgemeine Forst- und Jagd-Zeitung, Jahrg. 77, p. 309-314, 1901.

² Göppert, H. R. [Hysterium pinastri als Ursache der Schütte.] Verhandlungen, Schlesischer Forst-Verein, 1852, p. 67.

monest or only cause of blight, criticised the parasitic theory of the disease. The fungus now seems to be generally accepted as the commonest cause of the blight of pines in German nurseries,¹ though it is recognized that other factors may also cause blight. Because of the confusion arising from the controversy mentioned, the term "schütte" has often been made to cover indiscriminately all forms of blight. It seems to the writer that the best policy will be to restrict the English equivalent term, "needle-cast," to the damage done by *Lophodermium pinastri*.

In Germany infection is said to take place between the end of July and the middle of September. The first reddening of isolated needles occurs in late September. In a very late fall the needles may turn brown and mature *Lophodermium* fruits appear before winter. Ordinarily the disease works very slowly during the fall and winter and rapidly in March and April. By May, in severe attacks, scarcely a green needle remains. Even with practically all the needles killed, the weakened plants are frequently able to resume growth at the terminal bud, though diseased trees are less able to survive transplanting than those not attacked. In some cases the parasite in the infected needles is said to enter the stem and kill it also.

The juvenile needles formed during the first year persist for a long time after death, while needles of the mature sheathed form are shed soon after death as a result of the formation of a cork separation layer. It is this early shedding of diseased needles which gives rise to the name of the disease. Spermatia are first formed on the fallen needles. By the end of July mature ascospores appear, capable of infecting healthy needles and thus completing the life cycle of the parasite. It is not certain that in this country the life history of the fungus would be the same as has been described for Germany. Some of the confusion concerning etiology that has increased the difficulty of separating needle-cast from other troubles can be traced to the fact that Ebermayer's blight, as well as death of roots from early fall freezing, may presumably cause the rapid death of the plants in early spring.

In needle-cast and related needle diseases the following characters may be expected:

- (1) The first indication of disease in the needles will be the appearance of light brownish green spots. These will not be as likely as most of the physiological diseases to attack the tips of the needles first.

- (2) Ordinarily the needles on any one part of the plant will not all die at the same time.

¹ Haack. Der Schüttepilz der Kiefer. Zeitschrift für Forst- und Jagdwesen. Jahrg. 43, Heft 4, p. 329-357, pl. 4; Heft 5, p. 402-423; Heft 6, p. 481-505, 1 fig., 1911.

(3) Even when all of the needles die at nearly the same time, there will not be the simultaneous death of the roots which occurs in sun scorch.

(4) There will not be the same relation of the disease to dry weather and dry sandy soil as in sun scorch.

(5) Beds which have been protected by fungicidal sprays will not be so likely to be attacked as others.

In Germany needle-cast is said by Stumpff¹ and others to be controlled by spraying with Bordeaux mixture in July and August. There is no guaranty that the same measures will be effective in this country. If the disease makes serious trouble in any American nurseries, spraying at different times of the year should be tested, using the 4-4-50 or 6-4-50 Bordeaux mixture containing 2 or 3 pounds of soap per barrel.

Ebermayer has attacked the evidence supporting the parasitic origin of needle-cast, saying, among other things, that Bordeaux mixture may protect not by preventing the entrance of fungi so much as by decreasing transpiration. The writer's experience with the 4-4-50 soap-Bordeaux mixture may be of interest in this connection. A heavy application a short time before the occurrence of an attack of sun scorch in seed beds of *Pinus divaricata* at the Halsey nursery had not the slightest effect in decreasing the loss from sun scorch, as shown by a comparison of parallel sprayed and unsprayed beds. The shade afforded by a "half-shade" slat frame in one of these beds at this time gave absolute protection against the disease. This indicates that the effect of Bordeaux mixture in reducing transpiration at critical times is negligible.

PESTALOTZIA NEEDLE BLIGHT.

Pestalotzia funerea Desm. is very common in dead coniferous needles in the United States. Tubeuf² considers it the probable cause of a twig-blight of cypress trees. In the United States, Spaulding³ induced needle disease on seedlings of *Pinus ponderosa* one month old by spraying with spores from a pure culture of this fungus. A test by the writer on 1-year-old white pine (*Pinus strobus* L.) under moist-chamber conditions, using cultures from jack and Rocky Mountain yellow pines, was without result. A further test on 1-year-old stock by Dr. Spaulding also gave negative results. Attempts were made by the writer to infect green shoots on old trees of arbor vitæ (*Thuja occidentalis* L.), some of which had been injured by punc-

¹ Stumpff. Die Schütte und ihre Bekämpfung. Zeitschrift für Forst- und Jagdwesen, Jahrg. 32, Heft 11, p. 675-687, 1900.

² Tubeuf, Karl von. Diseases of Plants Induced by Cryptogamic Parasites. English edition by W. G. Smith. London, New York, and Bombay, 1897, p. 493-499.

³ Spaulding, Perley. A blight disease of young conifers. Science, n. s., v. 26, No. 659, p. 220-221, 1907.

turing, or heating, or both. Viable spores from pure cultures recently isolated from arbor vitæ were used. No results were obtained. While the fungus is presumably parasitic in nurseries under some conditions, the amount of damage it has caused is unknown. Spraying with fungicides before infection takes place should prevent damage by it.

OTHER NEEDLE DISEASES.

Various fungi which have been very little studied in this country cause needle diseases in American forests. Though none have yet been reported as causing disease in our nurseries, there can be little doubt that some of them have made, or at least will soon make, trouble in nurseries in this country. Much of the comparative freedom from needle diseases of American nurseries, even those in the more moist regions, has probably been due to the fact that most of our nurseries are not in forests. So far as needle diseases are concerned, it will be best to avoid forests of the same species as will be grown in the nursery in choosing sites for new nurseries. Of the fungi mentioned in the literature on needle diseases, which is mainly European, the following species will especially bear watching: *Lophodermium macrosporum* R. Hrtg. on spruces, *Lophodermium nervisequium* D. C. on firs, *Lophodermium laricinum* Duby on larches, and *Lophodermium brachysporum* Rostr. on white pine. *Lophodermium brachysporum* has been reported by Spaulding¹ as parasitic on needles of young white pines in Maine. Other species of this genus and species of *Hypoderma* and *Sphaerella* are also likely to prove more or less parasitic. It is probable that there are parasitic strains of needle fungi in foreign countries which if brought into this country will damage our nursery stock more than any of the fungi we now have. No practicable quarantine or inspection system will be able to keep out these diseases entirely. Nurserymen should avoid bringing in foreign pests by using home-grown stock as far as possible. So far as is now known seed may safely be imported, but bringing in growing stock should be discouraged.

The Atlantic seaboard and portions of the extreme western and northwestern sections of the country, where the climate is especially moist during parts of the year, are the most likely to suffer from needle diseases. In the Middle West, where atmospheric conditions are relatively dry, past experience indicates little trouble with needle parasites in unmulched beds. It is presumable that other needle parasites, like the one causing needle-cast, will be found to be preventable by spraying before infection takes place.

¹ Spaulding, Perley. The present status of the white-pine blights. U. S. Department of Agriculture, Bureau of Plant Industry, Circular 35, p. 10, 1909.

ROOT-ROTS.

Many soil-inhabiting fungi grow on dead roots of both seedlings and transplants. There undoubtedly are soil fungi which can kill living roots when conditions are favorable. A species of *Fusarium*¹ is said to have caused loss by killing pine roots in a Vermont nursery. Mycelial growth on roots, such as is there described, has been frequently observed by the writer, though in only part of the cases was it associated with any apparent injury to the plants.

Rhizoctonia sp. (probably *Corticium vagum* B. and C.), which causes damping-off of very young seedlings, sometimes continues to work in patches till the seedlings are 2 months old or even more. On sandy soil, when seedlings from 5 to 9 weeks old are killed, the youngest and deepest parts of the roots are usually first attacked. At Halsey roots of Rocky Mountain yellow-pine seedlings about 7 weeks old have been attacked at points as much as 11 inches below the ground surface. In many seedlings as old as this the older parts of the roots resist the entrance of the fungus which has rotted the younger parts and throw out new root branches, so that recovery takes place without any evidence of the damage being shown by the plant above ground. While we ordinarily consider damping-off as the death of very young, succulent seedlings, the killing of seedlings from 5 weeks to 2 months old by *Rhizoctonia* is merely a continuation of the earlier and more typical damping-off and to a certain extent is influenced by the treatments which control the early damping-off. For practical purposes, therefore, only the relatively small number of cases of root-rot which occur after the plants are 2 months old are considered as blight; root-rot of stock less than 2 months old is classed as damping-off.

Root-rot of stock more than 2 months old does not appear to have become a serious source of loss in this country. Until more is learned concerning it nothing of value can be said as to characteristic symptoms or control measures.

UNCLASSIFIED DISEASES.

STEM GIRDLE.

In Wisconsin, Oregon, Colorado, and New Mexico the stems of 2 and 3 year old conifers in nurseries have been found constricted or girdled in a peculiar manner just above the ground line, and sometimes abnormally large just above the point of girdling. The bark at the point of constriction is dead and often loose. The trees may continue in apparently good health for some time after the girdling.

¹ Gifford, C. M. The damping off of coniferous seedlings. Vermont Agricultural Experiment Station, Bulletin 157, p. 149-151, 1911.

but at length gradually become yellow and die. Scotch pine, Rocky Mountain yellow pine, white fir (*Abies concolor* (Gord.) Parry), Douglas fir, and Norway spruce have been found affected, the latter most seriously. A very similar trouble is known in Germany under the name "Einschnürungskrankheit." It is figured by Tubeuf.¹ Various coniferous and broad-leaved species are affected, beech, fir, and spruce being most prominently mentioned. In Germany *Pestalozzia hartigii* Tub. is found on the constrictions and is considered to be the cause of the disease. The causal relation has not been proved by inoculation, despite extensive experiments by Fischer.² Of the few cases of disease observed by the writer the fungus has been found fruiting on the lesions in a single case on Rocky Mountain yellow pine from New Mexico. In this case the bark had been dead so long that it had become loose. While the stem girdle in this country may be due to *Pestalozzia hartigii*, proof is lacking.

The important practical facts are that the disease does not often do serious damage, and that the only method of combating it which can be suggested is to destroy all diseased material. All girdled trees with bark killed entirely around the stem are certain to die and should be pulled out and burned at once without waiting for them to turn yellow.

MULCH INJURY.

In nurseries where beds are covered with a mulch during the winter to prevent heaving or winterkilling, heavy losses sometimes occur while the mulch is on the beds or just after it is taken off. While mulch injury usually occurs during the winter it is an entirely different thing from the winterkilling in unmulched beds. The general experience of nurserymen has been that the disease was worst where the mulch was heaviest, or where it was composed of fine material which packed down into a close covering. While the injury is the result of the use of mulch, the immediate cause of death is unknown. While physical factors may be entirely responsible, it is quite likely that death is due to some needle parasite whose work is favored by the conditions which prevail in mulched beds. What is very likely the same trouble occurs occasionally under a light mulch, or even under no mulch at all, when there is heavy or very late snow.

In two cases the writer has had opportunity to examine injured white-pine and Douglas-fir seedlings shortly after the mulch was removed. In both bases the roots were still healthy despite the death of the needles and in many plants of the upper parts of the stems.

¹ Tubeuf, Karl von. Diseases of Plants Induced by Cryptogamic Parasites. English edition by W. G. Smith. London, New York, and Bombay, 1897, p. 492.

² Fischer, C. E. C. Note on the biology of *Pestalozzia hartigii*, Tubeuf. Journal of Economic Biology, v. 4, No. 3, p. 72-77, pl. 7, 1909.

This survival of the root after the death of the top distinctly separates this trouble from those of the root-rot and sun-scorch types. The experience of a number of nurserymen shows that the disease can nearly always be prevented by using only loose, light material to mulch with and mulching no more than is absolutely necessary. Spraying with Bordeaux mixture just before the mulch is put on is worth a test at any nursery where mulch injury is frequent.

RED-CEDAR BLIGHT.

In western nurseries where red cedars (*Juniperus virginiana* L. and *J. scopulorum* Sarg.) are grown for ornamental planting there is a great deal of trouble with a blight of unknown origin. A number of nurseries have nearly or entirely stopped trying to grow cedar on this account. The disease is described as sometimes working suddenly over a considerable area of seedlings and transplants. Since attacks are said to occur when adjacent pines are perfectly healthy it is not likely that sun scorch is responsible. In large transplants all the needles on specific twigs and branches die at once, indicating a parasitic twig blight. In the cases observed by the writer there was no evidence of any constriction of the twigs such as Tubeuf¹ has figured for *Pestalozzia funerea* twig-blight on *Chamaecyparis menziesii*.

So little is known concerning the trouble that no recommendations for its control can be made. It is suggested that the nurserymen who have the most trouble with the disease conduct experiments separately with watering, moderately heavy shading, and frequent spraying with soap-Bordeaux mixture on numerous small-scale experimental plats scattered through their beds. One of these methods should prevent or partly prevent the disease. A comparison of attacks on treated and untreated plats should give information both as to the nature of the disease and the best control method.

MECHANICAL ROOT INJURY.

It often happens that trees which die in the nursery can be pulled up very easily. Examination shows that the root has been either broken or eaten off 1 to 3 inches below the surface of the soil. This presumably is done by grubs. This type of loss is mentioned merely to keep it from being confused with any of the types of blight described in this paper.

CONCLUSION.

A number of different blights concerning which little has been known do considerable damage to conifers in nurseries in the United States. The increasing amount of forest planting and the danger

¹ Tubeuf, Karl von. Loc. cit.

that imported stock will bring in serious tree diseases make it especially important that methods of controlling these blights be found, in order to encourage the growing of planting stock in this country. The writer has not only experimentally determined the cause and distinguishing features, but also the control methods for sun scorch, the most serious of these blights, and by following his recommendations the disease has been controlled in nurseries where it had before done serious damage. Distinguishing characters and preventive measures for the two other commonest blight types, winter-killing and mulch injury, have also been determined. An account of what the writer has been able to learn from his own work and the experience of others with the other types of blight is also given. Distinguishing characters and control methods have not been found for all of the types.

It is seldom that a case of nursery blight can be diagnosed merely by examining a few specimens of diseased trees. It is hoped to carry this investigation so far that each nurseryman will be able to identify for himself, by general observations, all of the types of blight which attack his nursery beds and to take the necessary steps for preventing further losses.

The writer wishes to acknowledge his indebtedness to Mr. W. H. Mast and Mr. R. G. Pierce for their cooperation in the work at the Halsey nursery, to Dr. H. L. Shantz for helpful advice, and to Dr. Perley Spaulding, under whose general direction the work was conducted, for advice and the use of his specimens and unpublished data.

SUMMARY.

The following are the types of blight most likely to cause losses of coniferous nursery stock in the United States:

(1) *Sun scorch*.—This is the commonest summer trouble. The roots die before or at the same time as the tops. Death is caused by excessive water loss. It usually occurs when the air is hot and dry and the soil around the roots is dry. The disease is worst on sandy soils, in crowded beds, and on raised parts of beds. On sandy soils it may kill suddenly and in definite patches. Successful preventive measures tested by the writer are watering, shading, and avoidance of crowding. In nurseries located on mineral soils the humus content should be increased.

(2) *Winterkilling*.—The tops of the plants dry out when the soil is frozen so that the plants can not take up water. The preventive measures most used consist of a light straw mulch on the beds and windbreaks.

(3) *Mulch injury*.—The tops die in winter as a result of being mulched. This happens while the mulch is still on, or occasionally

just after it is removed. The roots do not die till some time after the tops. The immediate cause of death is unknown. The disease may be prevented by avoiding heavy, close mulches. Spraying with soap-Bordeaux mixture just before the beds are mulched in the fall may also be of value.

(4) *Needle diseases*.—There are a number of needle-destroying fungi, some of which are certain sooner or later to cause damage in the nurseries in the more moist parts of the United States. They have so far done little damage in our nurseries and have been little studied. Spraying with Bordeaux mixture at the proper time will presumably prevent damage from any of them. The proper times for spraying are not yet known. The importation of European stock should be discouraged, in order to avoid bringing in parasites which have not yet reached this country.

(5) *Red-cedar blight*.—A great deal of blight occurs in red-cedar seedlings and transplants. The cause and methods of prevention are unknown. Shading, watering, and frequent spraying should be tested.





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(PROFESSIONAL PAPER.)

THE DEATH OF CHESTNUTS AND OAKS DUE TO ARMILLARIA MELLEA.

By W. H. LONG,
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INTRODUCTION.

Some time ago complaint was made to the Office of Investigations in Forest Pathology that the chestnut trees on certain areas near New Berlin, in Chenango County, N. Y., were rapidly deteriorating; that some were dead, others dying, and the remainder in poor health. Since this region is not in the known range of the chestnut bark disease (*Endothia parasitica*), the dying of the chestnut could not be attributed to this fungus, and the writer was therefore detailed to make an investigation of the trouble.

CHARACTER OF THE TIMBER EXAMINED.

Two areas of woodland of about 20 acres each were examined. The timber consisted of a mixed stand of chestnut, oak, and white pine, with a sprinkling of poplar, maple, and hemlock. All of the timber above a diameter of 6 inches, or even less, was being cut. Much of it had only recently been felled, while some was still uncut. The oak and chestnut were being made into railroad ties and the pine into lumber. Both tracts of timber were located on the level tops and slopes of rather rough ridges. The average age of the chestnut and oak was from 60 to 100 years. One of the areas had been partially logged over 20 years ago; the other had never been logged. There have been no forest fires in either tract, so far as known. As the two areas were close to each other and similarly located, they will be treated as a whole in this discussion.

CHARACTER OF DATA OBTAINED.

In addition to the felled trees of chestnut and oak, dead, dying, and badly diseased standing trees were studied. No attempt was made, on account of limited time, to examine the roots of any number

NOTE.—A record of the results of field investigations of the condition of chestnut and oak in Chenango County, N. Y.

of living trees. A record was kept of each felled and each dead tree. The data taken included the diameter of stump, the average height of stump (which was usually about 1 foot), the diameter of the rot in the stump, the height to which the rot ascended in the butt of each tree, the cause of each kind of rot found, the root-rots present, the number of dead trees, the cause of death, the number of dead trees blown down, and any other facts bearing on the health of the trees. Data on 902 felled trees were obtained. Of this number, 477 were white oaks, 302 chestnuts, 61 red oaks, 45 poplars, and the remainder maples, service berries, and pines.

GENERAL CONDITION OF THE CHESTNUT.

HEALTH OF THE TREES.

All of the chestnut trees over 18 inches in diameter were found to have diseased tops; that is, some were "stag headed," while all had one or more large dead branches on them. Many of the larger chestnut trees, especially those somewhat isolated on the edges of the ridges, had been struck by lightning. These trees were not killed outright, but in many cases tops, branches, and strips of bark of varying sizes had been killed. In a few instances the bark had been partially stripped from the tree, but usually the lightning left little or no external evidence of immediate injury. A careful examination, however, showed that wide strips of bark had been killed, especially near the bases of the trees, and that little or no callus had formed around the wounds. In the majority of cases the wounds had not healed, but were gradually increasing in size. This increase was always greater at the base of the tree and could usually be traced directly to the parasitic action of the fungus *Armillaria mellea*. The typical rhizomorphs, or "shoe strings," of this fungus were present at the bases of the trees and extended 5 to 20 feet upward beneath the bark.

Of the tops, 75 per cent were infected by a pocketed or piped rot (Pl. I, fig. 1) caused by the fungus *Polyporus pilotae*, which had apparently entered through the old dead branches so common on the upper parts of chestnut trees in this region. In addition to this top-rot, 46 per cent of the felled trees were infected with butt-rot, the bulk of which was also caused by *Polyporus pilotae*.

RATE OF GROWTH.

The chestnut bark disease was not found in the region examined, but the chestnut trees, and also the oaks and poplars, were undoubtedly dying here and there from other causes. The annual rings in the chestnuts show that these trees had made a fairly rapid and vigorous growth during the first 20 or 30 years; then came a period of much slower growth, culminating in a period in which the annual



FIG. 1.—HEART-ROT IN CHESTNUT CAUSED BY *POLYPORUS PILOTAE*.

The fungus entered at the dead branch and has moved downward into the heartwood of the tree proper.

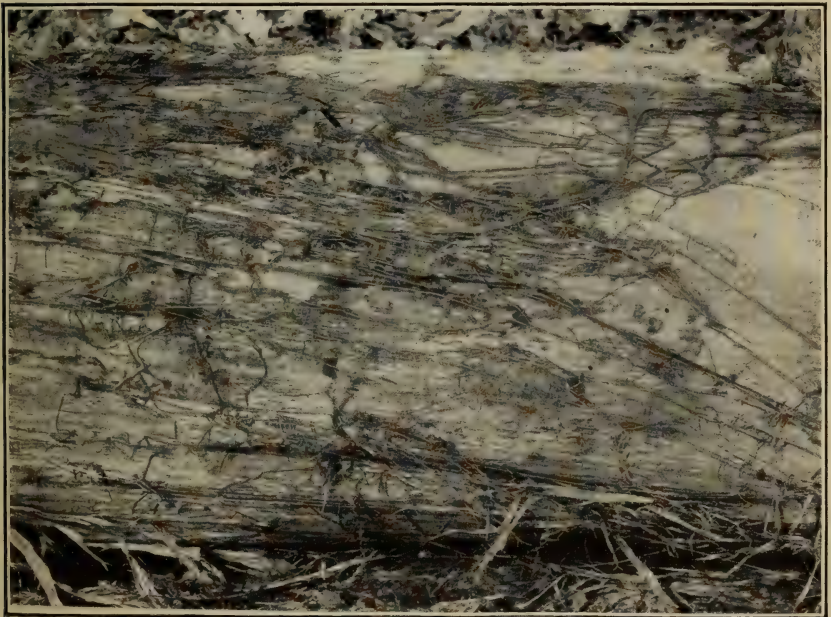


FIG. 2.—“SHOE STRINGS” OF *ARMILLARIA MELLEAE* BENEATH THE BARK OF A FELLED CHESTNUT WHICH HAD BEEN KILLED BY THIS FUNGUS.

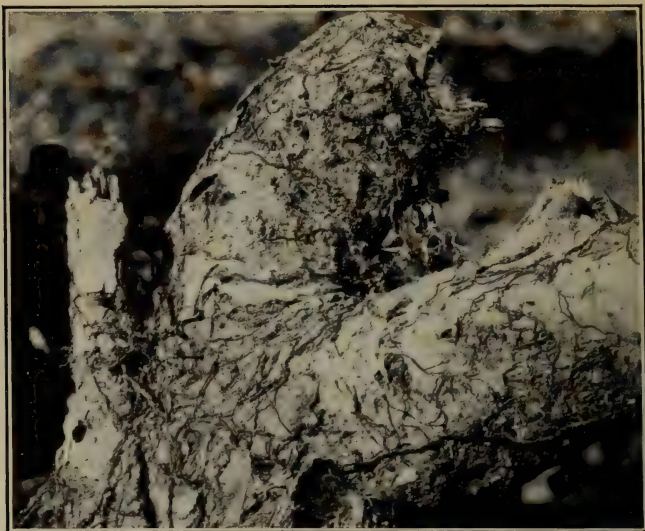


FIG. 1.—“SHOE STRINGS” OF *ARMILLARIA MELLEA* ON THE DEAD ROOTS OF A WIND-THROWN WHITE OAK.



FIG. 2.—*ARMILLARIA MELLEA* UNDER THE BARK OF TWO CHESTNUT TREES WHICH ARE JOINED AT THE GROUND.

The fungus has killed the tree in the foreground and has passed over to the other tree, where it has killed the bark for a distance of 8 feet upward and about one-third of the distance around the base of the tree.

increment was less than 1 millimeter in radius. In those trees which had been killed the annual increment in radius for the last 6 to 10 years of their life was only one-third to one-fourth of a millimeter. The average rate of increment was found to be 25 millimeters in diameter for $7\frac{1}{2}$ years of growth. This small increment indicates that the chestnut in this region is growing under very unfavorable conditions.

A clearer idea of how slowly these chestnuts have grown can be obtained by comparing the diameters of a few of these trees with those of chestnuts grown under more favorable conditions in other localities. For this purpose data are used which were published in 1905 by the Bureau of Forestry in Bulletin 53, entitled "The Chestnut in Southern Maryland," by Raphael Zon. The Forest Service has permitted the writer to use some unpublished data consisting of growth-diameter measurements made in West Virginia and Tennessee by Walter Mulford in 1905-6 and in Hyde Park, Dutchess County, N. Y., by J. G. Peters in 1905. The data from Hyde Park, where the growth conditions for chestnuts were favorable, are especially valuable for comparing with the growth data of chestnuts in New Berlin, as the two localities are in the same State. The growth data of chestnuts grown in Connecticut, included in Table I, were obtained by compiling the figures contained in Bulletin 154 of the Connecticut Agricultural Experiment Station, entitled "Chestnut in Connecticut and the Improvement of the Woodlot," by Austin F. Hawes.

TABLE I.—*Diameter measurements and average ages of chestnut trees.*

DIAMETER, BREAST HIGH (INCHES).

Age and diameter.	New York.		Connecticut.	Maryland.	Tennessee.	West Virginia.
	New Berlin.	Hyde Park.				
Age (years):						
10.....	1.6	2.5	.....	3.75	0.7	0.5
20.....	3.7	4.9	3.4	6.67	3.1	2.4
30.....	5.7	7.2	6.4	9.25	5.6	4.3
40.....	7.6	9.4	9.5	11.5	8.2	6.4
50.....	8.3	11.4	12.6	13.4	11.2	8.4
60.....	9.5	12.9	15.6	15.2	13.7	10.4
70.....	10.7	14.0	18.7	17.3	16.0	12.5
80.....	11.9	.....	21.7	18.1	18.4	14.4
90.....	12.0	.....	24.8	19.1	20.3	16.3
100.....	11.2	.....	27.8	20.0	21.7	18.2
110.....	11.3	.....	30.8	.....	22.7	19.9

AGE (YEARS).

Diameter, breast high (inches):						
6.....	32	25	29	17	32	38
8.....	46	31	35	25	39	48
9.....	56	38	39	29	44	53
10.....	65	43	42	33	46	59
11.....	80	47	45	38	49	63
12.....	90	54	48	43	53	67

From Table I it is readily seen that the chestnut at New Berlin, N. Y., has made a much slower growth than the trees from any of the other localities listed.

GENERAL CONDITION OF THE WHITE OAK.

Of the oaks in this region, the white oak (*Quercus alba*) predominates, but is intermixed with the red oak (*Q. rubra*). The tops of all the oaks appeared healthy, no "stag heads" or large dead branches being present. There was very little butt-rot of any kind in the boles. This was especially true of the area that had never been logged. In this area there occurred only 5 per cent of butt-rot and no top-rot of any kind. On the area which had been partially logged once there was a greater percentage of butt-rot due to injury to the standing timber from bruises on the roots and butts of the trees exposed to injury in logging. On this area the oak had 21 per cent of butt-rot, as against 5 per cent on the unlogged tract. Of this butt-rot, 87 per cent was caused by *Hydnum erinaceus*, which by decay makes hollows and is capable of entering through slight bruises on the trees, as well as through fire scars and other deep wounds.

ARMILLARIA MELLEA ON CHESTNUTS, OAKS, AND POPLARS.

The "shoe strings" of *Armillaria mellea* were found very abundantly on the roots and under the bark of the butts of chestnuts, oaks, and poplars. They were also occasionally found on maples and on service berries (*Amelanchier* sp.), but none were found on the white pine. These "shoe strings" were also common in the soil around the bases of the diseased and dead trees. On some of the dead chestnut trees these "shoe strings" had grown upward under the bark for 15 or 20 feet. In many instances they had made a perfect network of strings over the sapwood (Pl. I, fig. 2). There could be no reasonable doubt that this fungus was killing the chestnut and oak, since trees were found in all stages of decline when it was present. Wherever a dead piece of bark on the base of a tree was removed, the brown or black rhizomorphs of this parasite were found beneath it. In such cases a watery zone of dying bark of a dark-brown color marked the boundary line between sound and diseased tissue. Sometimes only a very small area of the bark was affected, although the roots on this side of the tree were already dead and the outer layers of the sapwood were more or less decayed. The rotten sapwood is watery, white in color, soft, and easily broken. On a chestnut tree 18 inches in diameter this fungus had killed an area 14 inches wide at the ground and extending 15 feet upward, while the "shoe strings" had grown up under the bark a distance of 8 feet. The top of this tree was dead. In three instances where chestnut trees had been struck

by lightning this disease was found following up and enlarging the wounds. Many of the white oaks killed by this fungus had been blown down. In every case the upturned roots were covered with a network of the black rhizomorphs (Pl. II, fig. 1). Several groups of two to four chestnut trees which had originated from sprouts around a common stump were found killed by this root-rot. Plate II, figure 2, shows two trees from a common base, one being already dead and the other badly diseased. In the latter the bark and roots on the side adjacent to the dead tree were killed for about one-third of the distance around the base, and the rot had extended up the tree 8 feet under the bark.

PERCENTAGE AND SIZE OF CHESTNUTS KILLED BY *ARMILLARIA MELLEA*.

Of the 302 felled chestnut trees examined, 64, or 21 per cent, had been killed by the *Armillaria* root-rot. The average diameter of these killed trees was 12 inches; the largest chestnut killed was 26 inches and the smallest 3 inches in diameter. Trees of all diameters between these limits were found diseased and killed. Of these trees, 10 had a diameter of 3 to 5 inches, 13 of 6 to 10 inches, 22 of 11 to 15 inches, and 19 of 16 to 26 inches. From this it follows that a greater percentage of the large chestnut trees was killed by this root-rot than of the smaller and younger trees. Of the 64 chestnut trees killed, 41, or 64 per cent, were over 10 inches in diameter. The average diameter of these 41 trees was 16 inches. In the white oak, just the reverse occurred; a greater percentage of the smaller and younger trees was killed than of the larger and older ones.

PERCENTAGE AND SIZE OF OAKS KILLED BY *ARMILLARIA MELLEA*.

Of the 477 oaks checked, 130, or 27 per cent, had been killed by the *Armillaria* root-rot. The average diameter of these killed trees was 7 inches, as compared with 12 inches in the chestnut. The largest oak killed was 18 inches and the smallest 2 inches in diameter. Trees of all sizes between these two extremes were affected. Of these white oaks, 39 ranged in diameter from 2 to 5 inches, 70 from 6 to 10 inches, and 20 from 11 to 15 inches, with only 1 over 15 inches. Of these 130 white oaks which had been killed, 84 per cent were less than 11 inches in diameter and only 16 per cent were over 10 inches in diameter, as compared with 64 per cent in the case of the dead chestnut trees in the same locality.

Of the white oaks killed by this root-rot, 46 had been overthrown by the wind, while only 2 of the dead chestnuts had been blown down. Of the wind-thrown oaks, 26 were from 6 to 8 inches in diameter, showing that the smaller as well as the larger sizes of white oaks were not as easily uprooted as those of medium diameter.

NUMBER AND SIZE OF POPLAR TREES KILLED BY *ARMILLARIA MELLEA*.

In addition to the dead chestnuts and oaks, the writer counted 29 poplar trees which had been killed by this root-rot out of a total of 45 examined. Many of these were small and much suppressed, although there were 12 that ranged from 6 to 9 inches in diameter. These larger poplars were not suppressed and under normal conditions ought not to have died.

GENERAL DISCUSSION OF THE DISEASED CHESTNUTS AND OAKS.

Why a larger percentage of small white oaks should be killed than of small chestnut trees is difficult to explain from the data at hand. However, it seems to be evident, judging from the location of the smaller white oaks which were killed, that the majority of the trees under 11 inches in diameter were much suppressed and for this reason would perhaps succumb more quickly to disease than trees growing under more favorable conditions. Nothing was found to indicate that the larger white oaks which had been killed were in poor health before they were attacked by this disease. It would seem that the disease, having gained a foothold in the soil, simply spread to the large white oaks and finally killed them. As far as could be determined, the fungus *Armillaria mellea* was the primary cause of their death. No white oaks in this region were seen which had been struck by lightning; this was in marked contrast to the number of chestnut trees in the same territory which had been struck.

The only explanation which can be offered for the small percentage of young chestnut trees which had been killed by the root-rot is that the present stand of chestnuts originated mainly from sprouts, and the young trees therefore had the large root system of the parent stump from which to draw nourishment. As a result, their growth would be very vigorous during the first 10 or 15 years of life. Under such conditions one would not expect a hemiparasite like *Armillaria mellea* to attack them as readily as it did the suppressed young oaks. This, however, does not explain why the disease has killed so many of the older and larger chestnut trees, unless the old stumps acted as a breeding ground for the mycelium until it obtained a foothold in the living trees. The chestnuts undoubtedly were growing under unfavorable conditions, a fact proved by the very small annual increment. This would make them more subject to diseases of this type. The weather conditions in the past may have been such as to weaken the trees and thus make them more susceptible to this rot. For instance, in the year 1913 the chestnut trees had lost two sets of leaves from late frosts, and at the time this investigation was made (June 19, 1913) the third set of leaves was not fully developed, and many of the trees were so badly injured that they apparently were not going to leaf out at all.

AREAS INFECTED BY *ARMILLARIA MELLEA*.

Ten distinct badly diseased areas of varying sizes were found in which the *Armillaria* root-rot had killed many trees. On one area 40 yards in diameter, both chestnuts and oaks of large size had been killed, including 6 chestnuts with diameters of 8, 8, 10, 12, 14, and 16 inches, and 4 oaks with diameters of 8, 13, 14, and 14 inches, respectively. Another rather large area had 34 dead trees scattered over it; of these there were 25 white oaks, 6 chestnuts, and 3 poplars. These trees ranged from 3 inches to 26 inches in diameter. On none of these diseased areas were all of the trees killed; some were alive and apparently in good health. This root-rot apparently was much worse where the soil was very damp, or even wet, during certain portions of the year.

Mr. H. M. Sears, of the Forest Service, in a report entitled "Deterioration of Blight-Killed Chestnut in Northern New Jersey," mentions the presence of the rhizomorphs of *Armillaria mellea* beneath the bark of some of the dead chestnut trees. No evidence was advanced, however, to show that this fungus had attacked the chestnut trees before they died.

ARMILLARIA MELLEA ON CHESTNUTS IN NORTH CAROLINA.

AREA EXAMINED.

On a recent trip through North Carolina, the writer found a rhizomorphic root-rot prevalent on the chestnut near Mount Airy, N. C., which is apparently the same as that found in New York. As the investigations in North Carolina were devoted primarily to the heart-rots of trees, very little time was given to this root-rot problem. However, some data on the character and extent of the disease were taken. The area studied was located about 6 miles east of Mount Airy, near Brim, N. C.

CHARACTER AND GENERAL CONDITION OF THE TIMBER.

The timber was located on the ridges and slopes and consisted of a mixed stand of chestnut and oak growing in a rather thin, more or less rocky soil with a red-clay subsoil. Chestnut oak (*Quercus prinus*) was the principal species of oak, but white oak (*Q. alba*), black oak (*Q. velutina*), and red oak (*Q. rubra*) were also present. All of the chestnut over the area examined was deteriorating, 90 per cent was stag headed and much was actually dying, while from 20 to 30 per cent was already dead. There was little or no sprout reproduction from the bases of the affected trees. Because of the rotted condition of the roots, the dead and dying trees in this region are easily blown down. According to resident millmen, this dying of the chestnut has become very pronounced during the last fifteen to twenty years.

The chestnut over this area originated mainly from seedlings, and, judging from the large annual increment, it made a healthy and vigorous growth before this trouble appeared.

NUMBER AND CONDITION OF THE INDIVIDUAL TREES EXAMINED.

The roots of 71 dead or badly diseased trees were examined. Of this number, 64 were chestnuts, 5 black oaks, 1 a chestnut oak, and 1 a sassafras. Of the chestnuts, 55 were already dead and 23 of them had been blown down when the studies were made. This afforded an opportunity to examine the condition of the roots. Nine of the living chestnuts studied were either dying or badly stag headed. Chestnut trees of all sizes were found dead or dying. Of the 64 chestnuts studied, 7 ranged in diameter from 4 to 10 inches, 23 from 11 to 20 inches, 29 from 21 to 30 inches, and 5 had diameters greater than 30 inches. An occasional black oak was found dead or badly stag headed, especially when adjacent to the worst affected chestnuts. The chestnut oaks, however, seemed to be vigorous and in the best of health. Especially valuable data were obtained from a wind-thrown chestnut 38 inches in diameter, which had been living but was badly stag headed when blown down. This tree was blown down only 11 days before the data were taken. The condition of its roots and stool was, therefore, exactly the same as when alive. When this tree was overthrown, several of the most superficial roots were still alive, but all of the deeper roots were dead. The sapwood of the dead roots was white rotted and covered with a network of black rhizomorphic strands. This rot was gradually encroaching on the living roots and killing them. The tree stood on the top of a rocky red-clay ridge, with the bulk of its roots within 2 feet of the surface of the soil.

All of the 71 trees examined had the "shoe strings" of *Armillaria mellea* on their roots. They were also found in a few instances extending from 3 to 8 feet upward beneath the bark on both living and dead trees. As a rule, however, the rhizomorphs were inconspicuous and were confined mainly to the roots and stools of the affected trees. The area studied was very limited, and no attempt was made to examine the roots of a large number of living trees. The data given here are therefore too meager to justify any positive opinion as to the amount of damage done by this root-rot in North Carolina. However, the prevalence and apparent destructiveness of this fungus over the area examined seem to point to it as very probably an important factor in the gradual recession of the chestnut in that State. If such an organism is at work, it would in a large measure explain the hitherto unexplained phenomena associated with this recession, such as the lack of reproduction from sprouts and the failure of the chestnut to reoccupy its former territory. A more extended investi-

gation covering the entire range of this recession may or may not show the presence of this root-rot as abundantly over the other regions involved as it is at Brim. The identification of this root-rotting organism as it occurred both in New York and in North Carolina was made from the rhizomorphic strands present on the affected trees. No sporophores were found, as the time of the year during which the diseased trees were examined was not the proper season for their appearance.

CONCLUSIONS.

(1) The chestnut near New Berlin, N. Y., and at Brim, N. C., is deteriorating. This is clearly shown by the small annual increment during recent years, by the thin sapwood, by the large percentage of diseased and stag-headed tops, and by the number of dead and dying trees. This decline is probably due to several factors, one of which is the root-rotting fungus *Armillaria mellea*, but it should be noted that in spite of these facts the chestnut bark disease (*Endothia parasitica*) is not present in these localities.

(2) *Armillaria mellea* can become an active parasite under favorable conditions, especially in chestnuts and oaks, killing not only suppressed trees in the forest, but also those that are growing under more favorable environments.

(3) The prevalence and apparent destructiveness of this fungus over the area examined in North Carolina seem to point to it as very probably an important factor in the gradual recession of the chestnut in that State.





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(PROFESSIONAL PAPER.)

NEW FACTS CONCERNING THE WHITE-PINE BLISTER RUST.¹

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INTRODUCTION.

In a recent publication² the writer gave the latest information regarding the white-pine blister rust up to the spring of 1913. The past season has brought forth several additional developments, which are of great importance.

THE SITUATION AT GENEVA.

Since 1906, when Stewart first discovered the presence of *Cronartium ribicola* upon Ribes at Geneva, N. Y., the disease has been found there in several different years.³ This occurred in spite of the total destruction of the Ribes found affected in 1906 and the apparent absence of the æcial stage of the fungus on the neighboring white pines.³ In the spring of 1913 the New York State department of agriculture took up the matter, and a special effort was made to locate and examine every white-pine tree within the diseased area, with the result that two trees about 15 years old were found by Inspector Maney bearing the fruiting bodies of the fungus. They were promptly destroyed. These evidently had been diseased for a long time, probably since they were 3 or 4 years old. No definite

¹ This paper is intended to supplement the previous publication, Bureau of Plant Industry Bulletin 206, entitled "The Blister Rust of White Pine." It is, therefore, as brief as possible, and care has been taken not to duplicate statements made in that publication. These two bulletins are necessary in order to secure complete information regarding this disease.

² Spaulding, Perley. The present status of the white-pine blister rust. In U. S. Dept. Agr., Bur. Plant Indus. Circ. 129, p. 9-20, 6 fig. 1913.

³ Stewart, F. C. Pine blister rust and currant felt rust. In West. N. Y. Hort. Soc. Proc. 58th Ann. Meeting, p. 122-124. 1912.

Stewart, F. C., and Rankin, W. H. Can *Cronartium ribicola* overwinter on the currant? In Phytopathology, v. 4, no. 1, p. 43. 1914.

Jordan, W. H. Director's report for 1906. N. Y. State Agr. Exp. Sta. Bul. 284, p. 341-342. 1906. Director's report for 1912. N. Y. State Agr. Exp. Sta. Bul. 356, p. 559. 1912.

NOTE.—This paper contains additional information concerning the white-pine blister rust that was collected during the season of 1913. It is of interest to foresters, tree experts, nurserymen, and owners of ornamental and forest plantations of 5-leaved pines.

information concerning their origin could be obtained, but it is believed that they were imported when 3 or 4 years old, that the disease came with them, and that they have been serving ever since as a center of infection each season for the *Ribes* in that vicinity. During the season of 1913 the disease appeared on but few *Ribes* bushes near the two trees above mentioned. The pines of the vicinity are to be held in quarantine and inspected each spring. In spite of the recent pessimistic opinion of those most directly concerned in the matter,¹ there is every reason to believe that the disease will soon be eradicated at this point, now that the center of infection is finally located. The conclusion that "complete eradication of the disease is no longer possible" is apparently meant to apply to the entire country and is based on the fact that blister rust was established at Geneva and the supposition that it was established in other places in New York, Massachusetts, and Connecticut. Now that the disease is well in hand in the Geneva area (the most dangerous one known at that time in the entire country²), there seems to be no sufficient reason for giving up the fight against as dangerous a disease as this promises to become if unchecked. This is especially true in view of earlier statements as to the seriousness of this disease.³

NEW OUTBREAKS.

Early in July the writer received specimens of white pine affected with blister rust from a point in northern Vermont which had not been previously known as harboring the disease. Inquiry showed that it was present upon native trees in that vicinity, this being the first known instance in this country. A visit was immediately made to determine the facts in the case, and the disease was found in the ornamental plantings of a large private estate. The original source of infection is unknown. It is quite possible that a few imported white-pine trees were obtained years ago, although it is definitely known that most of the trees in the vicinity are native and grew in the near-by woods. At any rate, the disease has been in some of the trees about 10 years, judging from the location of the cankers and their general appearance. Of the total number of white-pine trees in that vicinity, about 150 in all, more than 50 were found to be visibly affected by the disease. How many may later develop blister rust is, of course, unknown, but probably 5 or 10 per cent will do so. Already about 33½ per cent have it, which should be sufficient to convince the occasional skeptic that this will be a serious disease⁴ if allowed to run its course in this country.

¹ Stewart, F. C., and Rankin, W. H. *Cronartium ribicola* and the proscscription of *Ribes nigrum*. (Abstract.) *In* *Phytopathology*, v. 3, no. 1, p. 73. 1913.

² Stewart, F. C., loc. cit.

³ Stewart, F. C., loc. cit.; Jordan, W. H., loc. cit., 1912.

⁴ Clinton, G. P. Notes on plant diseases of Connecticut. *In* *Conn. Agr. Exp. Sta. Rpt.*, 1909-10, p. 733. 1911.

The disease had evidently reached a stage at this place where its future spread would be much more rapid than it has been in the past. About 100 feet from the apparent original center of infection was a single black-currant bush (*Ribes nigrum*),¹ some 50 to 75 red-currant bushes (*Ribes vulgare*), and about 30 gooseberry bushes (*Ribes grossularia*). The leaves of the black currant were covered with telia and uredinia of *Cronartium ribicola*, but only a very few sori were found on the red currants and none on the gooseberry leaves. Evidently the conditions have been extremely favorable for the propagation and spread of the fungus ever since the *Ribes* were set in that locality. All of the *Ribes* have been removed and destroyed, and the diseased trees and parts of trees are being cut out and destroyed.

Late in the fall of 1912 the writer received a specimen of blister rust on leaves of *Ribes* from Ipswich, Mass. In the spring of 1913 two small white pines which bore fruiting bodies of the fungus were found by the State nursery inspector near the diseased *Ribes* bushes. These were destroyed, and it was believed that the disease had been eradicated. It appeared later, however, about half a mile away, on leaves of *Ribes nigrum* and of *Ribes vulgare* of the variety Red Cross. The abundance of the fungus led the writer to suspect the center of infection to be near by. An examination promptly revealed evidences of the disease on neighboring white pines of about 10 and 18 years of age. Steps are being taken to remove the diseased trees and branches and also the black currants.

In 1913 Clinton² reported an outbreak of this fungus on the leaves of black currants near Meriden, Conn., late in 1912. He examined the vicinity, but could find no infected white pines in that locality. The origin of this outbreak is still unknown, and for this reason the situation is perhaps more dangerous than that in any other locality where the disease is now known to occur.

SERIOUSNESS OF THE DISEASE.

In the Vermont locality mentioned one large white pine about 2 feet in diameter and quite mature from the lumberman's standpoint was found to have the disease scattered throughout the top. Branches of all sizes up to 4 inches in diameter were thus affected. From the condition of this tree it was very easy to understand how a large tree may be killed by very severe attacks of this fungus, since it is a mere matter of time before an attacked branch or tree trunk is killed above the point of infection. One tree about 20 years of age, which had been infected in the trunk about 10 feet from the ground,

¹ The three *Ribes* mentioned are cultivated species which have been introduced into this country from Europe. The last (*Ribes grossularia*) is usually placed in a different subgenus than are the two first; by some authors it is placed in a separate genus.

² Clinton, G. P. Notes on plant diseases of Connecticut. In Conn. Agr. Exp. Sta. Rpt., 1912, p. 347-348. 1913.

had its top entirely dead above that point. Numerous small branches were found on other trees in a similar condition. A number of other trees of the same age apparently have been killed in a similar way, as they have been dying for years and have had to be removed, one or two at a time. While it takes a long time for the destructiveness of this disease to reach its climax in any given locality, there can be no doubt that if it finally becomes established and generally distributed in our forests it will be the worst enemy the white pine has here, as is stated to be the case in certain European countries.¹ It has become so thoroughly established in Europe that there is no hope of eradicating it there, but there is yet time to suppress it here if the danger is once generally realized. Even with conditions as they are in Europe, one of the most prominent plant pathologists of Germany recommends the energetic fighting of this disease.² If such action is advisable in Europe, even more drastic action is certainly proper in this country.

CAN THIS DISEASE WINTER OVER ON RIBES?

Late in 1912 F. C. Stewart asked the writer to take part in a cooperative experiment to try to determine whether this disease can winter over on dormant *Ribes* stock and thus be carried from one place to another in stock which has previously been diseased. Two hundred 2-year-old *Ribes nigrum* plants which had been heavily rusted by *Cronartium ribicola* in the late summer and early fall of 1912 were sent to the writer at Washington, D. C., about December 1. They were promptly heeled in out of doors until February 1, when, according to agreement, they were potted and brought into the greenhouse. They started quickly and made a very vigorous growth. They were examined several times for the presence of *Cronartium ribicola*, but none was found. The experiment was concluded about May 20 because of the writer's absence after that date. Parallel tests were made at Geneva and Ithaca, N. Y., Lafayette, Ind., Amherst, Mass., and New Haven, Conn., 300 plants being used.³ The results were entirely negative. The evidence furnished by the

¹ Bos, J. Ritzema. Phytopathologisch laboratorium Willie Commelin Scholten. Verslag over de inlichtingen gegeven in 1900. *In* Landbouwk. Tijdschr., jaar 9, p. 77. 1901.

Fisher, W. R. Experimental plantations at Coopers Hill. *In* Quart. Jour. Forest., v. 3, no. 3, p. 229. 1909.

Fron, Georges. Nouvelles observations sur quelques maladies des jeunes plants de Conifères. *In* Bul. Soc. Mycol. France, t. 27, no. 4, p. 476-481. 1911.

Lind, Jens. Danish fungi as represented in the herbarium of E. Rostrup, p. 281-283. Copenhagen, 1913.

Neger, F. W. Die Nadelhölzer . . . p. 110-111. Leipzig, 1907.

Somerville, W. Peridermium strobil, the blister of Weymouth pine. *In* Quart. Jour. Forest., v. 3, no. 3, p. 232-236. 1909.

Watson, J. G. The Woburn forests. *In* Gard. Chron., s. 3, v. 52, p. 422. 1912.

² Tubeuf, Carl von. Über die Verbreitung von Baumkrankheiten beim Pflanzenhandel. *In* Mitt. Deut. Dendrol. Gesell., p. 156-163, 1904.

³ Stewart, F. C., and Rankin, W. H. Can *Cronartium ribicola* overwinter on the currant? *In* Phytopathology, v. 4, no. 1, p. 43. 1914.

natural occurrence of the disease shows that dormant *Ribes* stock does not harbor the fungus. But all the evidence is negative (except that mentioned earlier by the writer)¹ and is subject to certain limitations, as is all negative evidence, when general conclusions are drawn from it. That is, it does not effectually dispose of possible rare exceptions, which may occur only once in thousands of cases. The practical conclusion is that *Ribes* plants do not carry the fungus over winter and that an outbreak of this disease on *Ribes* is to be attributed to the presence of neighboring white pines which have the blister rust. Hence, when the disease is found on *Ribes* leaves a special effort should be made to locate and destroy infected trees.² Ewert³ has recently published a paper showing that thorough spraying with Bordeaux mixture, with special care to cover the lower surface of the leaves, will almost completely control this fungus upon *Ribes nigrum*. It is suggested that in the future when diseased pine trees are found early in the summer, any *Ribes* in the vicinity be promptly sprayed on both sides of the leaves, in order to reduce the resulting infections and the outbreak of the uredo stage. Spraying should not be resorted to except as a temporary expedient, as just indicated.

About May 15, 1913, several plants of *Ribes nigrum* were isolated and an attempt was made to inoculate them with telial material furnished by Stewart which had been kept out of doors all winter. This attempt was unsuccessful, as was also a similar one made by the writer in 1912 with fresh teliospores.

CULTIVATED VERSUS WILD RIBES.

A statement has been made implying that the cultivated species of *Ribes* are not dangerous factors in connection with this disease.⁴ All of our experience in this country shows that the contrary is true. In no known case has the disease been discovered on native wild species of *Ribes*, while it has been found in a number of cases on the cultivated species of *Ribes nigrum* and *Ribes vulgare*. The evidence shows that our native wild *Ribes cynosbati* and *Ribes prostratum* are resistant to the fungus, while *Ribes nigrum* is exceedingly susceptible, and some varieties of *Ribes vulgare* are quite susceptible. The variety Red Cross has been found in one instance to be seriously diseased. *Ribes grossularia* has been immune. The cultivated *Ribes* are much

¹ Spaulding, Perley. Notes upon *Cronartium ribicola*. In *Science*, n. s., v. 35, no. 891, p. 146-147. 1912.

——— The present status of the white-pine blister rust. In U. S. Dept. Agr., Bur. Plant Indus. Circ. 129, p. 17. 1913.

² Spaulding, Perley. Notes on the white-pine blister rust. (Abstract.) In *Phytopathology*, v. 4, no. 1, p. 41-42. 1914.

³ Ewert, R. Erfolgreiche Bekämpfung des *Cronartium-Rostes* auf der schwarzen Johannisbeere. In *Ztschr. Pflanzenkrankh.*, Bd. 23, Heft 8, p. 463-476, 2 fig. 1913.

⁴ Clinton, G. P. Notes on plant diseases of Connecticut. In *Conn. Agr. Exp. Sta. Rpt.*, 1909-10, p. 732 1911.

more dangerous than are the native wild plants, because many white-pine plantations are made on deserted farms. In such places the former garden currants persist for years, and the inspector often finds them in the midst of a plantation of imported pines. Moreover, nurserymen often keep stocks of white pines and *Ribes* in proximity to each other, which is dangerous if either has the disease. These facts do not mean that wild species of *Ribes* can be disregarded, but that both wild and cultivated species must be considered when control measures are undertaken.

PINUS EXCELSA A HOST.

In a recent publication Lind¹ mentions the Himalayan pine (*Pinus excelsa*) as a known host of the white-pine blister rust in Denmark. The writer is informed that the disease was found in 1913 upon young trees of *Pinus excelsa* in Massachusetts. Unfortunately, no specimens of it were saved, but there seems to be no doubt that *Pinus excelsa* is a host of this fungus and is liable to be affected by it in this country. This is the first time that the white-pine blister rust has been found here on any other species of pine than *Pinus strobus*.

AGE OF DISEASED WHITE-PINE TREES.

White-pine trees from 3 to about 75 years old having the blister rust have been seen. From 3 to 15 years the series was almost uninterrupted; then the ages were approximately 18, 20, 25, and 75 years. The trees of 25 and 75 years were diseased on the branches and not on the main stem, but below 25 nearly all have been affected on the main stem. The evidence seems to show that this disease has been present on small numbers of imported pine trees in this country since 1888, and perhaps longer.²

DISTRIBUTION OF SPORES OF CRONARTIUM RIBICOLA.

In 1912 the writer made some observations on the distribution of the spores of *Cronartium comptoniae* from *Pinus rigida* to *Comptonia asplenifolia*.³ The æciospores are so similar in size and shape to those of the blister rust on white pine that it seems probable that one would be distributed as far as the other under the same conditions. It was found that the æciospores of *Cronartium comptoniae* were blown about 30 feet from their point of origin. This led the writer to suspect that the æciospores of the white-pine blister rust would also be blown relatively short distances. Such has been the case in all those

¹ Lind, Jens. Danish fungi as represented in the herbarium of E. Rostrup, p. 281-283. Copenhagen, 1913.

² Spaulding, Perley. The blister rust of white pine. U. S. Dept. Agr., Bur. Plant Indus. Bul. 206, p. 36. 1911.

³ Spaulding, Perley. Notes on *Cronartium comptoniae*. In *Phytopathology*, v. 3, no. 1, p. 62. 1913.

not so much in the total number of diseased trees present as it does instances that the writer has had an opportunity to investigate personally and where the origin of the spores has been determined. Two instances, on the other hand, where no diseased pines were found, seem to indicate that the æciospores were blown long distances, though this is by no means a certainty. In the three instances examined by the writer in 1913, the Ribes were about 100 feet from the diseased pines. There is every reason to believe that the uredospores of the white-pine blister rust may be blown half a mile or more.¹

GENERAL RESULTS OF INSPECTIONS.

Some of the general results of the annual inspections made for the white-pine blister rust, beginning in 1909 and continued to the present time, are of interest. In the States north and east of Washington, D. C., about 4,000,000 white pines are known to have been imported since 1900. Probably 500,000 more have been privately imported, about which nothing is known, making a total of about 4,500,000 trees imported into these States. Of this number 1,725,000 are known to have been destroyed before they reached the hands of private individuals, leaving 2,775,000 which have been set out in lots ranging from 500 to several hundred thousand trees. The number of such known lots is approximately 200. The inspection of these trees has varied much, some having been inspected once, some carefully inspected for the first time in 1913, and still others carefully inspected each year since the discovery of the disease on pines in this country in 1909. The figures given in Table I cover only those plantations that have been continuously under inspection from the beginning.

TABLE I.—*Results of the continuous inspection of infected lots of white-pine trees.*

No.	Item.	Number.
1	Total trees inspected.....	910,000
2	Total trees found diseased.....	8,177
3	Total trees found with fruiting bodies of the fungus (data available for but 560,000 trees).....	938
4	Lots of trees inspected.....	150
5	Lots of trees where disease was found.....	88
6	Lots of trees where fruiting bodies of the fungus were found.....	45

In Table I, item 6 includes none of the lots counted in item 5, and the same is true of items 2 and 3. The same is also true of similar items in Table II.

In considering these results it must be remembered that a single tree with fruiting bodies of the fungus and in proximity to a currant bush may start an epidemic of the disease which may continue for years and may spread over an area of several square miles. In fact, this is practically what happened at Geneva, N. Y. The danger lies

¹ Stewart, F. C., and Rankin, W. H. *Cronartium ribicola* and the proscriptio of *Ribes nigrum*. (Abstract.) *In* Phytopathology, v. 3, no. 1, p. 73. 1913.

in their wideness of distribution. The fact that 938 trees bearing fruiting bodies of the fungus were found within a certain area is of no special significance unless we note that they were found in about thirty different localities which are scattered well over that entire area of thousands of square miles. Then we perceive that it is inevitable that the disease will become established in one or more of those localities unless efficient control measures are taken and faithfully continued until the disease is eradicated. As already indicated, this is not being done everywhere.

TABLE II.—Results of inspections of 80 lots of infected white-pine trees.

No.	Item.	Lots.
1	Trees found bearing fruiting bodies in 1910 and not afterwards.....	15
2	Trees found bearing fruiting bodies in 1911 and not in 1910 or 1912.....	3
3	Trees found bearing fruiting bodies one year and also each year afterwards.....	3
4	Trees bearing fruiting bodies not found at first, but which were discovered later.....	5
5	Diseased trees found at first, but not in later years.....	21
6	Diseased trees found continuously.....	12
7	Diseased trees found irregularly (does not include those in item 5).....	10

Items 1 and 2 show that in one-fifth of the lots the inspector apparently removed all the trees bearing fruiting bodies of the fungus in a single year, but in every such case trees were found thereafter which were diseased, but did not bear the spores of the fungus. In a single instance only, all of the diseased trees were apparently removed by the first inspection. Our experience to date decidedly discourages the idea that a single inspection is efficient in eradicating this disease. Item 5 apparently contradicts this statement, but these lots may easily have been cases where the inspector took everything showing any abnormality and reported it as suspicious, when the disease was really absent.

In a previous paper¹ the writer mentioned the apparent effect of cool weather in regulating the formation of telia of *Cronartium ribicola* in the greenhouse at Washington. This experience has been repeated the present season. Apparently, farther north, where the nights are relatively cool, this inhibition does not occur, as telia were found in northern Vermont on July 23.

In a recent publication,² which received limited distribution, the writer showed the inefficiency of inspection, except as a temporary expedient, in trying to eradicate this disease. The total destruction of infected lots of white pines was urged as being the only safe course. This means a considerable present loss, which, however, will be very slight when compared with the loss that will result if the blister rust is allowed to become established and to spread.

¹ Spaulding, Perley. Notes upon *Cronartium ribicola*. In Science, n. s., v. 35, no. 891, p. 146-147. 1912.

² Spaulding, Perley. The present status of the white-pine blister rust. In U. S. Dept. Agr., Bur. Plant Indus. Circ. 129, p. 9-20, 6 fig. 1913.





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PROFESSIONAL PAPER.

INJURY BY DISINFECTANTS TO SEEDS AND ROOTS IN SANDY SOILS.

By CARL HARTLEY, *Pathologist, Investigations in Forest Pathology.*

INTRODUCTION.

For several seasons the writer has conducted experiments in the application of disinfectants to pine seed beds for the purpose of controlling damping-off. Formaldehyde and various inorganic acids and salts have been tested. The work conducted at two of the nurseries with seed beds sown in the spring and summer has now been completed. The practical results of the disease-control work have already been briefly summarized.¹ Because of the interest of soil investigators as well as plant pathologists in the behavior of disinfecting agents in the soil, the data on injury to pine and weed seedlings by disinfectants are here published separately. Data on the effects of the disinfectants on the growth rate of pine seedlings are still being gathered from three nurseries, and it is hoped to publish these later.

Acknowledgments are due Dr. F. K. Cameron and others, of the Bureau of Soils, and Drs. Rodney H. True and F. D. Heald, of the Bureau of Plant Industry, for helpful suggestions.

SOIL CHARACTERS.

The nursery where most of the work was done is at Halsey, Nebr., in a valley among sand hills. The soil throughout the nursery area is quite uniform, both soil and subsoil being classed as fine sand. There is a fair amount of humus in the upper 10 to 12 inches, in some places extending to nearly 20 inches below the surface. Below 12 inches there is no humus in most of the nursery. The soil at the other nursery, that of the Pennsylvania Railroad, near Morrisville, Pa., is a light-gray sandy loam, with a fine, reddish, sandy subsoil which is rather nearer the surface than the subsoil at Halsey. Exami-

¹ Hartley, Carl, and Merrill, T. C. Preliminary tests of disinfectants in controlling damping-off in various nursery soils. *In* *Phytopathology*, v. 4, no. 2, p. 89-92, 1914.

nation by the Bureau of Soils of the United States Department of Agriculture shows the presence of the usual soil-forming minerals. The chemical and mechanical analyses are given in Table I.

TABLE I.—*Chemical and mechanical analyses of the nursery soils at Halsey, Nebr., and Morrisville, Pa.*

[The soil samples were taken from the upper 6 inches; subsoil from depths of 15 inches at Halsey and 12 inches at Morrisville.]

Analyses.	Percentage of soil.		Percentage of sub-soil.	
	Halsey.	Morrisville.	Halsey.	Morrisville.
Chemical constituents:				
MnO ₂	0.24	0.21	0.18	0.19
Fe ₂ O ₃	3.08	1.60	2.85	1.30
Al ₂ O ₃	14.93	8.72	14.95	6.20
K ₂ O.....	4.48	1.68	.80	1.88
P ₂ O ₅	Trace.	Trace.	.48	.11
CaO.....	.86	2.23	3.79	1.35
Total salts by bridge.....	.21	.39	.09	.08
N.....	.07	.03	.09	.05
CO ₂ (from carbonates).....	None.	None.	None.	None.
Ignition loss (two determinations averaged).....	2.41	2.93	.55	1.96
Lime requirements (CaO) per acre..... pounds..	2,450	1,750	2,450	1,750
Mechanical constituents (size of particles):				
Fine gravel, 2 to 1 mm.....	0	1.0	0	0.5
Coarse sand, 1 to 0.5 mm.....	3.0	10.9	3.5	8.6
Medium sand, 0.5 to 0.25 mm.....	9.5	16.1	15.4	13.4
Fine sand, 0.25 to 0.1 mm.....	58.1	28.9	61.3	30.5
Very fine sand, 0.1 to 0.05 mm.....	21.0	19.2	17.5	23.5
Silt, 0.05 to 0.005 mm.....	6.5	18.5	1.5	18.1
Clay, 0.005 mm. and finer.....	2.1	5.5	.8	5.2

The wilting coefficient, determined by the indirect method of Briggs and Shantz,¹ was 3.42 per cent for the surface soil and 1.5 per cent for the subsoil at Halsey, and 4.92 per cent for the surface soil and 4.73 per cent for the subsoil at Morrisville. The samples examined from Halsey were taken from 10 different points in the nursery, while the samples from Morrisville represent three different points.

EXPERIMENTS AT HALSEY, NEBR.

Experiments at the nursery at Halsey have been carried on in cooperation with the United States Forest Service during the past five years. Mr. Robert D. Rands assisted the writer during the year in which most of the data were secured, and Messrs. R. G. Pierce and Fred R. Johnson, of the Forest Service, rendered material assistance in the work.

DISINFECTANTS USED.

Part of the sulphuric acid used in the following experiments was C. P. (chemically pure), but most of it was a clear commercial grade, the acid used in most of the work here reported having a specific gravity of 1.84 and that used for the latest work a specific gravity of

¹ Briggs, L. J., and Shantz, H. L. The wilting coefficient for different plants and its indirect determination. U. S. Department of Agriculture, Bureau of Plant Industry Bulletin 230, 1912.

1.83. Repeated parallel tests of C. P. and commercial sulphuric acid failed to develop any difference in their effect on the seed beds. A part of the hydrochloric and nitric acids used was C. P. and part commercial. The ammonia used was the strongest commercial ammonia water obtainable from local druggists (ordinarily 26° Beaumé). The formaldehyde used was the so-called 40 per cent commercial solution. Because of the need of distinguishing between pure formaldehyde and this commercial solution the latter will be referred to as formalin. The general use of the term "formalin" for the commercial solution appears to have become approved by custom,¹ despite the fact that this term formerly applied only to the product of an English firm. The lime-sulphur used was a commercial solution with a specific gravity of 1.31. The mercuric chlorid used was C. P. and the cupric sulphate was the fully hydrated crystalline form. The copper acetate was neutral, containing a single molecule of crystallization water. The zinc chlorid was a technical grade, granular, guaranteed from 95 to 98 per cent pure. All lime used was air-slaked.

The unit of measure used throughout is the fluid ounce (29.574 c. c.) for the acids, formalin, ammonia, and lime-sulphur solution, and the avoirdupois ounce (28.35 grams) for the other substances. Except where otherwise stated, all of the disinfectants were applied in aqueous solution. When lime was used the powder was spread dry on the surface of the bed and was worked into the upper 2 or 3 inches with a rake. Two or three pints of water per square foot of seed bed was found a convenient vehicle for applying the disinfectants. Because of the variable moisture content of the soil the degree of dilution of the solution before application is not of the greatest significance. The amount of the disinfectant used per square foot of soil surface is given in all cases as the measure of the strength of the treatment.

PLANTS UPON WHICH OBSERVATIONS WERE MADE.

The seed beds on which disinfectants were used were sown with different species of pine. Jack pine (*Pinus divaricata*) was the species used in most of the work, while western yellow pine (*P. ponderosa*), Norway pine (*P. resinosa*), and Corsican pine (*P. laricio*) were also used, the relative frequency being in the order named.

Weeds of various types appeared in the seed beds in addition to the pines, and data as to their tolerance of disinfectants were also obtained. Cryptogams were represented by a large-stalked species of *Equisetum*, the algæ conspicuous in many nurseries being present to but a slight extent. Monocotyledons were represented by various grasses, *Eragrostis cilianensis*² being much the most common, while *Echinochloa crus-galli*, *Panicum barbipulvinatum*,² and *Chaetochloa*

¹ Perkin, W. H., and Kipping, F. S. Organic chemistry, new ed., p. 124. London, 1911. See also Webster's New International Dictionary, 1913.

² Determinations made by Mr. P. L. Ricker.

*viridis*¹ were also more or less common. The nurserymen pulled up most of the weeds before flowering, so that it was not possible to determine positively the relative frequency of the different grass species for each plat. The commonest dicotyledons were *Mollugo verticillata*,¹ *Portulaca oleracea*,¹ *Amaranthus retroflexus*,¹ *A. hybridus*,¹ *A. graecizans*,¹ *A. blitoides*,¹ and *Euphorbia glyptosperma*.¹

INJURY TO PINES BY SULPHURIC ACID APPLIED AT OR AFTER GERMINATION.

In the following cases sulphuric acid was applied to the beds after some pine seedlings had come up. Because of the great irregularity of germination in many beds the time of germination can be given only approximately. It represents as far as possible the date by which enough seedlings had appeared to constitute a fair stand. Most of the experimental plats were sown with jack pine. The results with this species appear in Table II.

TABLE II.—*Effect of sulphuric acid on seedlings of jack pine, at Halsey, Nebr.*

Number of plats treated.	Time of treatment.	Fluid ounce of acid per square foot.	Volumes of water.	Result.
4	{ On date of germination.....	0.172	128	All killed.
	{ 6 days after germination.....	.086		
	{ On date of germination.....	.086		
2	{ 6 days after germination.....	.043	256	Nearly all killed.
	{ 8 days after germination.....	.043		
	{ 13 days after germination.....	.043		
4	{ 1 day after germination.....	.086	128	Many killed.
	{do.....	.043		
	{ 3 days after germination.....	.043		
4	{ 6 days after germination.....	.086	256	{ More killed than in preceding experiment.
	{ 8 days after germination.....	.043		
	{ 21 days after germination.....	.043		
2	{ On date of germination.....	.021	512	Germination, 11.8 per cent.
	{ 2 days after germination.....	.021		
	{ On date of germination.....	.011		
2	{ 2 days after germination.....	.011	1,024	Germination, 13.8 per cent.
	{do.....	.011		
2	{do.....	None.		Germination, 14.7 per cent.

Half of the plats in Table II which were given the stronger solutions were sprinkled lightly with water immediately after each treatment. This watering had no evident effect in the plats treated with the 128-volume solution, but in four plats which received the 256-volume solution, followed by sprinkling, the stand of seedlings was more than twice as great as on four adjacent plats which were given the acid treatment only.

The results in the plats treated with the 512-volume solution indicate that a total of 0.043 ounce of acid per square foot applied before germination was complete was sufficient to prevent the appearance of some of the latest germinating seedlings, while 0.021 ounce in two applications had little or no effect. Further tests would be necessary to prove that injury can be caused by these very weak treatments.

¹ Determinations made by Mr. P. L. Ricker.

Acid was also used after germination on seed beds of western yellow pine. In the first test the percentage of the seedlings which died during the first 33 days after germination was determined for four plats, as follows:

Plat VIII-A.—On the twelfth day after germination, 0.086 ounce of acid in 128 volumes of water; repeated on the fourteenth and nineteenth days. Loss, 72 per cent.

Plat VIII.—Same acid treatment as VIII-A, but sprinkled lightly with water after each application. Loss, 33 per cent.

Plat 27.—On the sixth and sixteenth days after germination, 0.086 ounces of acid; 12, 14, and 19 days after germination, 0.043 ounce of acid; solution in 256 volumes of water. Loss, 21 per cent.

Plat 28.—No treatment. Loss, 23 per cent.

While the loss in plat 27 was slightly less than that in the untreated plat there is clear evidence that the acid killed the seedlings, as the parasitic loss in this plat was very much less than in the untreated plat.

The treatments on Plats VIII and VIII-A were practically duplicated on a seed bed 13 days younger, with the result that the losses for the first 20 days were 45 and 47 per cent, respectively, as compared with 16 per cent in the nearest check.

Further tests of sulphuric acid on germinating yellow pine were made during the two following seasons. In the first case, acid in 256 volumes of water was tested on beds which had received 0.188 ounce of formalin per square foot 40 days before sowing, a treatment which in itself had no appreciable influence. The results were as follows:

Plat 402-S.—Seven and again twenty-five days after germination, 0.125 ounce of acid. Germination, 64 per cent; loss after germination, 44 per cent.

Plat 402-N.—Seven days after germination, 0.125 ounce of acid. Germination, 51 per cent; loss, 30 per cent.

Check plat.—No acid. Germination, 68 per cent; loss, 62 per cent.

In this series, the effect of the acid was clearly to prevent the appearance of the latest germinating seedlings and to kill the youngest seedlings which had already broken through the soil. The heavier loss in the untreated plats is due to heavy parasitism, which the acid treatment almost entirely prevented.

The following season, using a solution of one part in 256 volumes of water, the following amounts of acid were applied to yellow-pine plats: 0.047 ounce per square foot on two plats three days after germination; the same amount on two other plats six days after germination; and 0.063 ounce on three plats seven days after germination. No noticeable injury occurred, though counts of the seedlings indicate that a few were probably killed by the acid.

Most or all of the injury caused by applications after the beginning of germination was due to injury to the roots. The light sprinkling with water just after acid applications, which in a number of

cases resulted in lessening injury, presumably exerted its effect through an immediate further dilution of the acid in the surface layer of soil. While part of the apparent freedom of the aerial parts of the plants from direct acid injury may be due to the slight tendency of liquids to adhere to pine seedlings, drops of 1 to 256 acid solution by volume (0.71 per cent by weight) frequently remained caught in the center of the whorls of cotyledons of yellow-pine seedlings. This localization of solution was not accompanied by any noticeable localized injury. The experience of Craig,¹ indicating direct injury to the foliage of grapes, plums, and apples out of doors by a solution containing but 0.25 per cent of the acid, was more closely duplicated in the case of seedlings of a grass resembling a common native species of *Panicum*, which occurred in some of the plats. Definite characteristic spots of dead leaf tissue were noted on the grass plants in a few cases in plats treated with a solution of 1 to 512 by volume (0.36 per cent). The solution adhering to the leaves is, of course, concentrated by evaporation of the water after application, so the injury from spraying with solutions is actually caused by a much stronger solution than that applied.

The tests outlined in the foregoing statement indicate that after the seed begins to germinate, any application of sulphuric acid sufficient to affect materially the activity of the damping-off parasites will cause the death of the radicles of some of the pine seedlings.

In applications after the beginning of germination, the concentration of the solution applied, as well as the amount of acid used per square foot, seemed distinctly related to the amount of injury to the roots of the seedlings. This indicates that the injury occurred very promptly after the application of the solution, before diffusion between the upper and lower layers of soil had time to equalize quantities and concentration of the soil solution. The younger parts of the roots were still in the upper 1 or 2 inches of soil in most cases at the time the injurious solutions were applied.

INJURY TO PINES BY SULPHURIC ACID APPLIED AT THE TIME OF SOWING.

In applications made at the time of sowing it was found that stronger treatments could be given without injury to the pines than when the treatments were delayed until germination. Stronger treatments were also required in order to control parasitic fungi, so that it was necessary in these tests also to work with treatments strong enough to cause injury to seedlings. Because of the numerous advantages of acid treatment at sowing, from the standpoint of disease prevention and nursery practice, a detailed study of the injury it causes to seedlings was undertaken with a view to prevention.

¹ Craig, John. Effects of dilute sulphuric acid on foliage. *In Canada Exp. Farms, Rpt.*, 1893, p. 101-102, 1894.

The procedure followed in treatment at sowing time was to (1) prepare the seed bed, (2) soak it with the disinfectant, (3) sow the seed broadcast, (4) cover with one-fourth inch of dry soil, and (5) apply the rest of the solution. The seed bed was not stirred up after the application of the solution was commenced. In no case in spring-sown beds has there been any indication that the treatments injured the pine seed before germination started, although the treatment, in strengths varying from 0.125 to 0.375 fluid ounce of acid per square foot, has been tested during the past three seasons in 19 different experimental series of jack pine, in 4 series each of yellow pine and Norway pine, and 1 series of Corsican pine. The proportion of germination in acid plats was nearly always higher than in the untreated plats (due to the prevention of parasites rather than to stimulation), and as high as in plats of soil disinfected by heat.

In jack-pine plats in which germination was reasonably prompt (12 to 14 days) and no special measures were taken to prevent injury to seedlings, many seedlings were killed or injured after germination began on plats which had received, respectively, 0.125 ounce and 0.141 ounce of acid per square foot at sowing, while 0.188 ounce per square foot always resulted in injury unless special protective measures were taken.

DESCRIPTION OF THE INJURY.

Injury to the seedlings in plats treated at or before the time of sowing took the form of damage to the growing apices of the radicles, with the result that extension of the root was stopped. Whether the meristematic apical cells were actually killed or simply lost their meristem qualities was not determined, though the former is the more probable. In most cases, root apices rendered incapable of growth retained their normal cream color for a few days after the injury and often recovered, though in severe cases they turned dark very soon. Plate I and text figures 1 and 2 show chemically injured seedlings. Plate I, figure 1, shows a healthy seedling, younger than the injured seedlings in figures 2, 3, and 4 of this plate, so that the darker color of the upper parts of the roots of injured seedlings is chiefly due to difference in age, rather than to the effects of the acid. The disproportionately short roots of the injured seedlings are especially noteworthy.

Ordinarily the growth of cells just back of the apex was not entirely prevented, so that the root tips became truncated as a result of the uneven growth. (Pl. I, fig. 2.) Distorted growth was also common. The capacity for absorption was usually retained by the injured roots for some



FIG. 1.—*Pinus divaricata* injured by acid. Root growth has just been resumed by two laterals after 11 days suspension. $\times 1\frac{1}{2}$.

time. Although injury to root apices commonly took place before the seedlings appeared above the soil, most injured seedlings came up, and when the soil around the short root was kept moist the growth of the stem and leaves continued for some time at a normal rate. All of the development of the aerial parts of the seedlings shown in Plate I, figures 2, 3, and 4, was made after the extension of the root had been stopped by acid.

Injured seedlings ordinarily lived till the surface of the upper part of the root became brown and presumably impervious, as in the older parts of the root in healthy seedlings after two or three weeks. In the worst injured seedlings this root browning seemed to take place somewhat earlier than in healthy plants. The decrease in diameter which is noticed in the older parts of normal roots at the time of browning was seldom observed in acid-injured roots. Because the injured seedlings were not able to develop new root tissue, absorption ultimately became impossible and death from drought ensued. The seedlings shown in Plate I, figures 2 and 3, have practically reached this condition, though both still appeared to be growing normally when they were dug up. Plate I, figure 4, shows a seedling injured at the same time as that in Plate I, figure 3, which has recovered by recommencing root growth.

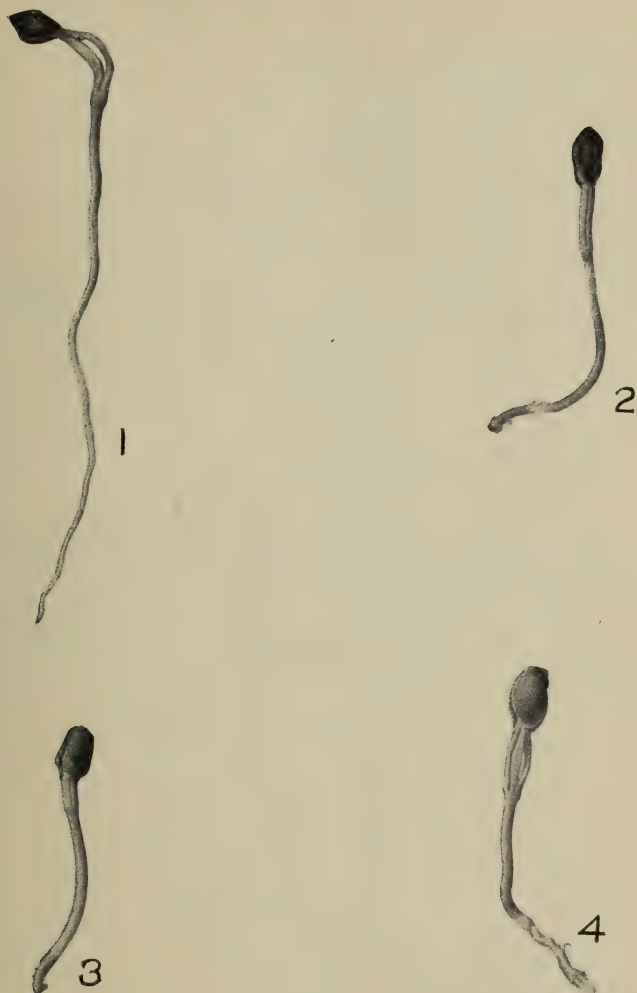


FIG. 2.—*Pinus ponderosa* injured by copper sulphate. Root growth has been resumed by a number of laterals. (Natural size.)

Where the roots of injured seedlings were very short, the plants died very soon, either because the soil was allowed to dry out to below the level reached by the short root or because the short root did not afford sufficient mechanical support for the top-heavy stem, and the seedling fell over or was washed out in watering. In the cases where injury was

earliest, so that the radicle had scarcely emerged from the seed coat by the time its tip was killed, the seedlings failed to appear above ground at all.

In a good many cases seedlings which had extended their roots a centimeter or more before injury ultimately recovered, either because of a resumption of terminal root growth, as shown in Plate I, figure 4, or by laterals starting just back of the apex, as in text figure 1. In such cases the parts of the seedlings above ground at no time showed any effect of the acid, and the only way in which the existence of injury could be detected was by examining the roots. Renewal



M. S. Hartley

HEALTHY AND ACID-INJURED PINE SEEDLINGS.

FIG. 1.—*Pinus divaricata*, healthy seedling. ($\times 2$.) FIG. 2.—*P. divaricata*, acid injured. ($\times 2$.) Probably not capable of recovery. The root growth was stopped before the seedling came up. The entire development of the stem and leaves above ground has taken place since the cessation of root growth. FIG. 3.—*P. laricio*, acid injured. ($\times 2$.) Injured when so little root had developed that there was no possibility of a resumption of growth. Illustration made 10 days after the killing concentration occurred. FIG. 4.—*P. laricio*, acid injured. ($\times 1\frac{1}{2}$.) Recovering by terminal resumption of root growth, as shown by the white root tip.

of root growth in injured seedlings was most commonly observed from 8 to 12 days after the original cessation of growth. Dr. Perley Spaulding has advised the writer that a year prior to the observations here reported he found this resumption of growth by laterals in injured western yellow-pine seedlings in experimental plats at Burlington, Vt.

It is seldom possible to recognize acid injury immediately after occurrence. Even after death takes place it is not possible to distinguish the deeper rooted injured seedlings from those killed by parasites, as by the time the seedling gives indications of death above ground the roots are too badly decayed to show what caused death. The best way to detect acid injury is to dig up healthy-looking seedlings in different parts of a plat a week or ten days after the first seedlings come up. The roots of the seedlings will be found to have the following characters:

(1) Acid-injured seedlings (Pl. I, figs. 2 and 3). Length, one-fourth to five-eighths of an inch. Color, if brown at all, tip will be as brown as the rest; root firm throughout.

(2) Healthy seedlings (Pl. I, fig. 1). Length, 1 to 3 inches. Color, upper part may be brown, but tip will be white.

(3) Damped-off seedlings (attacked by parasites). Length, usually same as healthy, but lower part may be entirely decayed, making root appear short. Some part of root examined will always be found soft from decay, while acid-injured roots are firm throughout.

NOTE.—Care is needed to distinguish between the short root of an injured seedling and a healthy root which has been broken off short by accident. With a little practice, the difference between a root tip and a broken end can be easily recognized.

PREVENTION OF INJURY BY LEACHING.

The first attempt to prevent injury to germinating seedlings from the residue of acid applied at sowing was by leaching. To different plats in a bed which had received 0.188 ounces of acid at sowing three days earlier, 4, 8, 12, and 16 pints of water per square foot, respectively, were applied. The plats were thereafter given sprinklings equal to 0.3 of an inch of rain often enough to insure germination, which took place 11 days after sowing. The heaviest initial watering, equivalent to 3.2 inches of retained rainfall, prevented most of the injury which occurred on the other plats, but not all. The plat receiving but 4 pints (0.8 inch) suffered heavily, while the amount of injury in the 8 and 12 pint plats was intermediate. In a second test, with an acid treatment of 0.211 ounce at sowing, followed by germination in eight days, a 6-inch watering was given three days after sowing. The bed was purposely allowed to become quite dry on the day of germination, and later examination showed that a small number of the pines were injured. In a third test, this 6-inch watering was used on a bed which had received 0.313 ounce of acid. The bed was allowed to become somewhat dry 10 days

after the acid treatment (1 day before germination), and a number of seedlings were injured. It was evident from the results obtained that these heavy applications of water leached out enough acid materially to reduce acid injury. Leaching is evidently not practicable as a method of preventing injury at most nurseries when germination is prompt. In a sandy soil when the weather is cold and germination requires 18 or 20 days, leaching soon after the application of acid may be a practicable method of preventing injury.

PREVENTION OF INJURY BY FREQUENT WATERING.

Fortunately two definite relationships which opened the way for developing a practicable method of controlling the injury to the pines were found. It was found that the amount of water in the soil at the time of germination bore a direct relation to the amount of injury, and that injury seldom occurred after the seedlings had sent their roots down five-eighths of an inch into the soil. The length of root shown in Plate I, figure 3, is typical of injured seedlings in general. The stoppage of growth of root apices in treated beds always occurred at times when the upper soil became relatively dry and while the root tips of germinating seedlings were still in the upper five-eighths inch of soil. Although the nurserymen water the beds often enough to prevent drought injury to the seedlings, great variation in the moisture content of the surface soil occurs. The upper one-fourth inch of soil at this nursery just after watering has frequently been found to contain 21 to 25 per cent of moisture, while at the same points the soil when dry has contained but 1.96 per cent of water, the average of 12 determinations made on different occasions. In a single period of 11 hours the moisture content of the surface soil at four different points in the seed beds dropped from 12.02 to 1.85 per cent. This of necessity caused great variations in the concentration of the soil solution. While beds were not ordinarily allowed to become as dry as this during the germinating period, they often became quite dry at the surface. A little below the surface the moisture content of the soil is more stable. The most rapid loss of moisture found in the seed beds from 1 to 2 inches in depth during the period in which determinations were made was a drop from 17 to 11½ per cent in a period of approximately 36 hours. This explains the relative safety of roots which have penetrated below the upper half inch of soil. That the root above the tip should resist relatively high concentrations of acid is in agreement with the results of Heald¹ and other investigators, who find the tip of the root to be the portion most sensitive to poisons. The difference in resistance between the very

¹ Heald, F. D. On the toxic effect of dilute solutions of acids and salts upon plants. *In Bot. Gaz.*, v. 22, no. 2, p. 130, 1896.

tip of the root and the tissue just back of it is well shown by the location of the new laterals developed by the seedling in figure 1.

In addition to the increased concentration of the acid solution already in the surface soil, due to the decrease of the solvent, acid from lower levels is presumably brought up to the surface by the capillary rise of the soil solution to replace that lost by evaporation. When the treated soil is soaked thoroughly with water and subjected to continuous evaporation for several days, but at a rate slow enough to avoid drying the surface soil entirely and breaking the capillary connection, this continuous upward movement of solution ultimately results in killing concentrations in the surface soil, even while it is still very moist. The problem of preventing injury to seedlings therefore becomes one of not only keeping the surface soil moist, but of maintaining a fairly constant downward movement of soil moisture, or at least of preventing a continuous upward movement for any considerable period, until after the roots of all seedlings have extended half an inch into the soil. Experience has shown that this can be done more easily with frequent light waterings than with heavier and less frequent applications.

A very few hours' delay in watering at a critical time has in some cases been enough to cause the killing of root tips by acid. Under certain conditions, as outlined in the foregoing paragraph, injury occurred before the beds appeared at all dry at the surface. Since appearances could not be relied on to show when watering was needed, systematic watering was tested. Furthermore, variation in individual judgment made necessary the use of measured quantities of water. Daily waterings equivalent to 0.4 of an inch of rain were not in all cases sufficient to prevent injury entirely. However, half this quantity applied twice as often, with the soil wet to begin with, was found sufficient to prevent all injury from moderate amounts of acid, even in very hot, dry weather. For large beds at this nursery which have received 0.188 ounce of acid at sowing, watering equivalent to 0.3 of an inch twice daily during the germination period has been recommended for summer use, so as to make certain that in the necessarily uneven large-scale work all parts of the bed will get at least 0.2 of an inch at each watering.

For work in cold spring weather, when the germination period is long, the expense of this special watering becomes considerable, and it further cools the soil to such a point that germination may be still more delayed. No such frequent watering is necessary to prevent injury in cool weather, but because of occasional hot, dry weather in early spring it is not safe entirely to abandon watering twice daily. A rather extreme instance of the variable temperature at Halsey was the rise of the temperature, as shown by a Weather

Bureau thermometer under a shelter 4 feet from the ground, from 37° F. at 8 a. m. to 98° F. at noon of the same day in April. The evaporation from white porous-cup atmometers set in the seed beds has varied from 14 to 59 c. c. for 24-hour periods 10 days apart, and still greater variations are to be expected from the darker soil surface. Hot, dry days increase the danger from acid injury both by increasing water loss and consequent acid concentration and by hurrying germination before the acid solution in the upper soil has had much time to decrease in strength. In view of the variability of weather conditions, the system now followed in preventing acid injury is to water daily in ordinary spring weather, every other day or even less often in misty or rainy weather, and twice daily when the temperature exceeds 80° F. In clear weather, waterings are to approximate 0.3 of an inch, while in cold and cloudy weather 0.2 of an inch is to be used. This watering system has proved practicable, and has been entirely successful in preventing injury to pines from acid applied at the time of sowing.

RELATION OF STRENGTH OF TREATMENT TO EXTENT OF INJURY.

The degree of dilution of the sulphuric acid in applications at sowing had no apparent relation to the amount of injury likely to result to the seedlings; that is, if 0.25 ounce of acid per square foot was applied, it made no difference, so far as noticed, whether it was dissolved in 64 or 192 volumes of water. There was not a sufficient number of tests with this factor as an independent variable to establish an entire lack of relation, but it is quite certain that within the limits given the amount of water used in making up the solution is not an important variable.

The first results indicated a rather surprising lack of constant relation between the amount of acid used per unit of soil surface and the amount of injury. In an early test of varying amounts of acid, all of which caused considerable losses of seedlings, the final stands in the plats were as follows:

Series 501.—Jack-pine plats; all except the check plats were treated with acid at sowing.

Eight check plats untreated. Final stands ranged from 71 to 163 per square foot; average, 122.

One plat, 0.125 fluid ounce of acid per square foot at sowing. Final stand, 216.

One plat, 0.141 ounce of acid. Final stand, 118.

Two plats, 0.188 ounce of acid. Final stands, 191 and 143; average, 167.

Three plats, 0.234 ounce of acid. Final stands, 107, 110, and 80; average, 99.

Two plats, 0.250 ounce of acid. Final stands, 23 and 153; average, 88.

One plat, 0.313 ounce of acid. Final stand, 94.

Two plats, 0.375 ounce of acid. Final stands, 11 and 116; average, 64.

In this series, as in those reported in the remainder of this paper, the plats received weights of seed proportional to their area.

In this series the variation between individual plats is great. Especially in the cases of the 0.250-ounce and the 0.375-ounce plats the variation between plats given the same acid treatments is much greater than the average variation between plats given different treatments or between the untreated plats; which are subject to much heavier variation from the action of parasites than the acid-treated plats. However, the averages indicate a distinct increase in the amount of injury as the quantity of acid is increased. The great individual variation between plats with the same acid treatment is to be explained by two factors which were not controlled. In the first place, different plats germinated at somewhat different times. Some plats therefore had a much greater average root length than others at the time the killing concentrations of the soil solution occurred. This greater root length resulted in the sensitive tip being farther down in the soil, where the acid solution does not become as concentrated as in the soil at the surface. It may also have been true here, as found by McCool¹ in his work with barium, strontium, sodium, and ammonium, that the root tips of seedlings a few days old are less susceptible to injury than those of seedlings which have just germinated, so that the age of the seedlings may have been even more important than the location of the root tips in making the older seedlings more resistant. Furthermore, those with the longer roots were not only less likely to be injured but also had a better chance to recover. (Compare Pl. I, figs. 3 and 4.) A more important variable factor in causing different results in plats with identical acid treatments was the watering during the germinating period. While all plats were watered at the same time, no attempt was made in series 501 to secure special uniformity in watering, and some became drier than others. A later test of different amounts of acid was made with plats sprinkled with measured quantities of water twice daily during the germination period. Germination took place nine days after the plats were treated and sown. The results are given in Table III.

TABLE III.—*Relation of the amount of acid applied and the thoroughness of subsequent waterings to the death of pine seedlings on plats treated with sulphuric acid at the time of sowing.*

[Seedlings per square foot surviving 44 days after germination.]

Water per square foot.	Treatment (ounces of acid per square foot).		
	0.211	0.250	0.313
2 pints at each watering.....seedlings.....		179	142
1.5 pints at each watering.....do.....	281	151	91
1 pint at each watering.....do.....	125	64	47

¹ McCool, M. M. The action of certain nutrient and nonnutrient bases on plant growth. N. Y. Cornell Agr. Exp. Sta. Mem. 2, p. 159-162, 1913.

The decrease in stand both with decreasing amounts of watering and with increasing amounts of acid was sufficiently consistent in this experiment to establish beyond a reasonable doubt the relationship, both of the amount of acid used and of the amount of watering done, to the acid injury. In the weakest acid plat with the intermediate watering, no appreciable injury occurred. Because of the variation in germination aside from the influence of acid, the results were not always quite as consistent as in this series, but no reason has been found to doubt the relation between the amount of acid and the extent of injury in beds treated at sowing.

INJURY TO PINES BY SULPHURIC ACID APPLIED BEFORE SOWING.

In treating beds with sulphuric acid to kill fungous parasites the attempt was made to evade toxic action on the seedlings by applying the acid a number of days before sowing. Jack pine was also used in most of these tests. In such cases the beds were ordinarily hoed and raked just before they were sown, so that the upper 2 or 3 inches of soil was well mixed after the acid was applied. In the plats treated at sowing there was the possibility that the injury was limited to the surface five-eighths of an inch of soil, simply because this layer of soil had acted as a trap for the acid, absorbing most of it at the time of application. In the case of plats treated before sowing there was no such possibility. The seeds were in most cases covered with about one-fourth of an inch of soil taken from the upper 1 to 1½ inches of the soil of a near-by area that had been given the same treatment as the plat sown. Considerable injury occurred in plats which received 0.25 and 0.375 ounce of acid nine days before sowing (20 days in all elapsing before germination), although the treated plats received approximately 1.6 inches of water five days after sowing, followed by 0.3 to 0.4 of an inch daily till after germination. The slight drying of the surface soil which resulted in the injury on these plats took place the first day after germination, 21 days after the application of the acid.

In another series, using the same species of pine, amounts of 0.281, 0.375, and 0.687 ounce of acid per square foot were applied 11 days before sowing, two plats receiving the latter amount. Four days after sowing, the plats were given approximately 1.6 inches of water, followed by waterings of approximately 0.3 to 0.4 inch on the sixth, eighth, ninth, tenth, and eleventh days from sowing. Germination took place on the eleventh day, 22 days after the application of the acid, and on the morning of this day the soil surface became somewhat dry, but not dry enough to cause appreciable drought injury in the nonacid plats. As shown by later examination of the length of the acid-injured roots, injury took

place at this time. It was most serious in the 0.375-ounce plat, mainly because it had become somewhat drier than the rest. Even the 0.281-ounce plat seemed more injured than the 0.687-ounce plats, which were not seriously affected. The activity of parasites, mostly, probably, *Pythium debaryanum*, in the soil in these plats during and after the time that this injury was occurring to the seedlings is a matter of some interest. The slight relationship between the amount of acid used and the amount of injury taking place in these plats 22 days after treatment emphasizes what has already been said as to the apparent equalization of strength of acid solutions of different original strengths in the soil as the concentration decreases.

Plats of jack pine which had been entirely killed by applications of 0.172 ounce of acid at the date of germination and 0.086 ounce six days later, 0.258 ounce in all, were resown with the same species 23 to 24 days after the first treatment, germination taking place 34 to 36 days after the first treatment. No serious injury occurred to the seedlings in this second sowing, though no special watering was given. Similar results were obtained with yellow pine in plats treated with 0.3 ounce of acid 39 days before sowing (50 days before germination), no serious injury occurring despite the entire lack of any special watering. In all cases, acid applied before sowing can be kept from causing injury quite easily by the watering methods used for beds treated at sowing. The tests indicate that if germination takes place at any time during the first month after 0.25 ounce of acid is applied to the beds it will be necessary to give more than the usual nursery watering during the germination period in order to insure freedom from injury to the seedlings. Though it is somewhat easier to prevent acid injury in beds treated several days before sowing, treatment at the time of sowing is so much more effective against the damping-off parasites that it is considered preferable.

RELATIVE RESISTANCE OF VARIOUS SPECIES OF PINE TO SULPHURIC ACID.

There was considerable difference in the amount of injury caused by similar acid treatments on different species of pine. Jack pine, as a rule, seemed most liable to serious injury, while yellow pine was least often damaged, and Norway and Corsican pines were intermediate. The resistance of yellow pine as compared with jack pine was especially evident in beds treated shortly after germination. Most of this apparent difference in resistance is due not to variations in the capacity of the root tips to endure acid, but to a difference in the rate of growth. Yellow pine has a seed approximately ten times as heavy as that of jack pine and sends its root down much

faster at the start. By the time a yellow-pine seedling breaks through the soil cover its root has gone down much farther into the soil than with jack pine at the same age, and the application of a disinfectant to the soil surface at this time is therefore much less likely to injure the yellow-pine root tip. When disinfectants are put on the soil at sowing, the root tips have not yet emerged from the seed, and yellow pine has no such distinct advantage over jack pine. There is still a difference in depth of planting, however, as yellow-pine seeds are usually covered deeper than those of jack pine and the root tips thus start at a lower level. The more rapid growth is also of some advantage in beds treated before germination, as injury occurs only at times of surface concentration. The root tips of yellow pine may get down far enough to avoid injury from a concentration which occurs before the tips of jack-pine roots have reached the safety zone. While yellow pine has been less often injured than jack pine by acid applied at the time of sowing, concentrations occurring while there was a large porportion of yellow-pine root tips in the surface soil have killed large numbers of seedlings. In one extreme case, in which 0.250 ounce of acid per square foot was applied 28 days before sowing and repeated at sowing, with germination following five to six days later, only two-thirds as many seedlings came up as in untreated plats, and of these over 90 per cent died, nearly all as a result of acid injury. On the whole, while yellow pine has been much less often injured by acid treatment, the evidence indicates little, if any, greater resistance of its root tips than that shown by jack pine.

Corsican pine shows injury in the same way as jack pine (Pl. I, figs. 2 and 3). It has a seed smaller than yellow pine, but still much larger than jack pine and producing a faster initial root growth. It therefore seems a little less liable to injury than jack pine, for the same reasons that yellow pine is less liable. Norway pine on the other hand, though having a larger seed than jack pine, makes a much slower initial root growth at this nursery. Its slightly longer germination period gives the acid more time for dissipation, but the indications are that the root tips of this species possess a slightly greater acid endurance than those of jack pine. Corsican and Norway pine have not been tested as much as the other two species, and the evidence obtained as to their relative resistance has less value.

INJURY TO MISCELLANEOUS PLANTS BY SULPHURIC ACID.

The watering given pine seed beds at the Halsey nursery resulted in the germination of great numbers of previously dormant weed seeds of the species listed on pages 3 and 4. These ordinarily began to appear a little later than the pines and continued to come up in con-

siderable quantities for the first two or three weeks, after which time the number which came up decreased.

Most of the data on the effects of sulphuric-acid treatments on weeds were obtained on beds treated at the time of sowing. The observations indicated marked differences between the species observed in their ability to grow in soil recently treated with acid. It was evident throughout that the pines were less easily injured than most of the weed species. On plats which received no special watering till after germination, 0.125 ounce and 0.141 ounce of sulphuric acid per square foot, respectively, at the time of seeding entirely prevented weed growth. The untreated plats in this series were fairly well covered with *Portulaca* and grass species and with a few plants of *Amaranthus*. At sowing in another series on a plat given very frequent watering, 0.125 ounce of acid failed to reduce perceptibly the number of common weeds. Another plat given the same treatment, which had also received 0.125 ounce of acid 13 days before sowing, showed entire freedom from weeds, with only partial injury to the pines. In repeated tests during successive seasons, treatments of 0.188 ounce of acid at the time of sowing regularly prevented practically all weed growth for the first three weeks after the germination of the pines. In some cases no weeds came up in treated beds until a month after the appearance of the pines. Beds treated with acid and so watered as entirely to prevent injury to the pines were nevertheless so free from weeds as a result of acid application that the cost of weeding the treated beds during the whole season has been only one-third that of untreated beds.

The appearance of *Equisetum* in acid-treated plats was of some interest. In an insufficiently watered acid plat on which the pines were seriously injured and on which not a single phanerogamic weed appeared, more *Equisetum* developed than in most of the untreated beds in the nursery. *Equisetum* was not a common weed anywhere, but it occurred more frequently in the acid beds than in the beds not treated.

The grasses throughout gave evidence of greater ability to endure the acid applied to the soil than did the dicotyledons. They were usually the predominant weeds and often the only ones in acid plats. This greater predominance of grasses over dicotyledons in the acid plats left little doubt as to their superior endurance of this treatment.

Unfortunately, few data were secured as to the factors which controlled the varying capacity of the different plants observed to endure acid applied to the soil. Most of the injury to the weeds did not occur in just the same way as to the pines. In the pines the commonest phenomenon was root injury, which allowed the seedlings

to come up, but caused them to die a few days later. With the weeds, nearly all that came up were quite certain to survive. The extent of the injury to weeds was shown chiefly by the small number of weeds which appeared on the acid plats as compared with the checks. The failure of seriously injured weed seedlings to appear above ground, as did most of the injured pines, may be due in part to a larger amount of stored food material in the pine seed and in part to a greater depth of soil over many of the weed seeds. It is barely possible that many still dormant weed seeds were killed at the time of the application of the acid. Some of the weed seeds in late-sown plats commence germination at or before the time of acid application, and are therefore probably killed at the time of application. The frequent occurrence of healthy *Equisetum* in beds where the acid killed the pines may be due entirely to the presence of old rootstocks and not to superior tolerance of acid. It has been suggested that the survival of grass where acid prevented the appearance of dicotyledons may be due to the branching habit of the grass roots, which makes injury to the tip of the primary radicle of less importance than with the plants which depend largely on a main taproot.

Despite the qualifications in the preceding paragraph it seems quite certain that a great many germinating weed seeds which were dormant at the time of the application of the acid and were deeper in the soil, and therefore exposed to lower concentrations of acid than the pines, were killed in much the same way as the pines by amounts of acid which would not injure the pines. The experiments indicate not only a distinctly greater tolerance for sulphuric acid in the pines than in the angiosperms most commonly represented in the beds, but within the angiosperms a somewhat smaller difference in tolerance between the grasses and dicotyledonous species was observed. Tests in water culture would be necessary to establish the differences in resistance of the various species observed in these experiments and to give the differences a quantitative value.

Treatments several days or weeks before sowing also had considerable effect on the number of weeds found in the seed beds during the first few weeks after the germination of the pines. The use of 0.3 ounce of acid 14 days before sowing, with sufficiently frequent watering after sowing to prevent injury to yellow pine, prevented the appearance of any dicotyledons for at least 43 days after treatment and allowed only a few grass seedlings near the edge of the plat and a couple of *Equisetum* plants. *Mollugo*, grass, and *Portulaca* seedlings were common in all the check plats in this series, and *Amaranthus* and *Euphorbia* were present, while *Equisetum* was at least no more common in the checks than in the acid plats.

In another series, in which watering was frequent enough to prevent injury to most pine seedlings, 0.25 ounce of acid nine days before sowing kept the plat free from all weeds except three grass plants for $1\frac{1}{2}$ months, and 0.375 ounce applied at the same time prevented weed growth of any sort. While grasses predominated in the untreated plats, they also contained many plants of *Mollugo*, *Portulaca*, *Amaranthus*, and *Euphorbia*, their frequency being in the order named.

In another series watered in the same way, 0.281 ounce of acid 11 days before sowing and heavier treatments applied to three other plats at the same time entirely prevented weed growth till 47 days afterwards, while the checks contained the same species as those in the former series.

In series 519, plats A, C, and D (Table VI), 0.25 ounce of acid had a distinct effect on the weed flora, practically the same as 0.375 ounce, in plats examined 66 days after application.

In another series, watered quite frequently after sowing in order to prevent acid injury, acid applied 14 days before sowing the pines was tested. On adjacent plats the upper 6 inches of soil was partially sterilized at about the same time by heating in a moist condition to above 80° C. in an oven, all parts of the soil being brought to at least that temperature and kept there for not less than 10 minutes. The results are presented in Table IV.

TABLE IV.—Weeds which appeared in plats disinfected by heat and by acid.

Plat.	Treatment (ounces of acid per square foot).	Weeds found 42 days after treatment.
Four checks.....	None.....	60 to 100 per plat; grass commonest, <i>Mollugo</i> and <i>Portulaca</i> frequent, <i>Amaranthus</i> occasional.
J and K.....	Heated.....	Grass much as in checks, and making more vigorous growth; 2 or 3 <i>Portulaca</i> plants, and 1 <i>Amaranthus</i> in each plat.
C.....	0.25	5 grass seedlings, with several <i>Mollugo</i> near edge.
F.....	.375	5 grass, with 1 <i>Portulaca</i> and 1 <i>Mollugo</i> near edge.
G.....	.375	4 grass.
D.....	.5	3 grass.

Evidently, unless the grass seed survived a temperature of 80° C. or more, it had been blown into plats J and K after treatment, and migratory ability may explain part of its predominance over the dicotyledons in acid-treated plats. The results in general, nevertheless, indicate that it is somewhat more resistant to acid than the dicotyledons.

RELATION BETWEEN TIME OF APPLICATION AND AMOUNT OF INJURY.

The foregoing experience with pines and other plants in beds treated with acid at the time of germination, at sowing time, and at various times before sowing, shows clearly, as would be expected, that

the time of germination is when acid applied to the beds will do the most damage to pine seedlings. The longer the period before or after germination takes place that the acid is applied the less danger there is of acid injury. The free acid in the soil solution would normally be decreased by diffusion or leaching downward into the subsoil, by adsorption or solid solution by the soil, and by chemical interaction with other constituents of the soil or soil solution. No attempt has been made to determine the relative importance of these different processes in the removal of the acid from the solution. It has seemed rather surprising that even with applications of acid as small as 0.25 ounce per square foot enough acid remains free in the surface soil three weeks after application to kill the tips of jack-pine roots and prevent the growth of most dicotyledonous weed species for $1\frac{1}{2}$ months. In soil containing large quantities of carbonates there could be no such length of persistence of free acid.

The amount of injury occurring in plats treated at different lengths of time before germination and the comparative lack of relationship between the amount of acid used and the extent of injury in cases where more than 15 days elapse between treatment and germination indicate that the rate of dissipation of the free acid in the soil solution decreases rapidly as the concentration decreases. Very small amounts of acid have proved extremely injurious to root tips in the soil at the time of application. While they lose this extremely toxic character in a very few days after application, the final reduction to a point where no injury occurs requires a relatively long time. The apparent relative stability of very low concentrations of acid in the soil solution is in agreement with the general course of removal of a solute either by diffusion or chemical reaction.

ADDITION OF NEUTRALIZING AGENTS AFTER THE APPLICATION OF THE ACID.

In different experimental series, plats treated with sulphuric acid before sowing were later treated with neutralizing agents to prevent acid injury. This procedure greatly decreased the effectiveness of the acid treatment against the damping-off parasites on whose account the work was being conducted, and so it was not exhaustively tested. In no case was lime applied to the extent of equivalent weights of the acid used.

The indications are that injury to pines may be prevented by small amounts of lime put on the beds a few days after the application of the acid. The results of the treatments are given in Table V.

TABLE V.—*Injury to roots in plats treated with sulphuric acid 12 to 16 days before sowing and later treated with lime.*

Plat.	Treatment (per square foot).			Days from acid treatment to—		Excess of acid over lime (fluid ounce per square foot). ¹	Percentage of acid which lime should neutralize. ¹	Injury to pines.	Weeds present 1½ months after acid application.
	Fluid ounce of acid.	Pints of solution.	Avoirdupois ounce of CaCO ₃ .	Lime application.	Germination.				
Pinus ponderosa (series 504-E).....	0.375	2	0.250	14	25	0.240	36	None.	Half as many as in check plats of same series.
P. divaricata (series 507): Five checks	None.	.....	None.	.....	.....	.....	.....	.....	Grass and Mollugo abundant; some Amaranthus, Portulaca, and Euphorbia in each plat.
M.....	.375	3	.250	6	20	.240	36	Slight.	Very few, mainly grass and Mollugo, but growth much more vigorous than in checks.
G.....	.500	2	.333	8	23	.321	36	None.	
K.....	.500	4	.333	9	24	.321	36	do.	
P.....	.500	4	.200	7	22	.392	22	do.	
E.....	.750	4	.333	7	22	.571	24	do.	
L.....	.750	2	.500	7	22	.481	36	do.	
O.....	.750	6	.500	7	22	.481	36	Slight.	
F.....	None.	.....	.125	.....	.....	.....	.....	None.	More weeds than in untreated plats, in vigorous condition.
C.....	do.	.....	.250	.....	.....	.....	.....	do.	
R.....	do.	.....	.375	.....	.....	.....	.....	do.	
A.....	do.	.....	.500	.....	.....	.....	.....	do.	
P. resinosa (series 514): Checks	None.	.....	None.	.....	.....	.....	.....	.....	Grass, Mollugo, Euphorbia, Portulaca, and Amaranthus.
J.....	.500	2	.333	5	24	.321	36	None.	Less than in checks; grass, Mollugo, and Euphorbia.
K.....	.500	4	.250	5	24	.365	27	do.	Less than in checks; grass, Euphorbia, and Amaranthus.
N.....	None.	.....	.500	.....	.....	.....	.....	do.	As for check.

¹ Based on equivalent weights, assuming for the commercial sulphuric acid a maximum specific gravity of 1.84 and a purity of 95 per cent. No allowance is made for impurities in the lime.

It appears that at least in plats M and O the acid applied was not reduced to two-fifths of its original amount during the first six or seven days after application. The injury in plat M, with its acid excess of only 0.24 ounce, when compared with the lack of serious injury in other plats with a greater excess of acid (notably plat E, with an excess 2½ times as great), is a further indication of the relative stability of weak acid solutions in the soil.

In the case of series 514, acid injury occurred in a plat treated with a relatively small amount of hydrochloric acid, and it is quite certain that only the lime prevented injury in plats J and K.

Ammonia was also tested, following sulphuric acid. On jack pine, 0.750 fluid ounce of acid applied 21 days before sowing was followed a few days later by 0.469 ounce of the strongest commercial grade of ammonia. No injury to pines occurred. Watering in this series was very frequent, so injury might have taken place with ordinary watering despite the lime used. In series 514, a red-pine plat treated with 0.562 ounce of acid 13 days before sowing, followed by

0.5 ounce of ammonia eight days before sowing, suffered no injury. In this case the heavy acid treatment would probably have resulted in injury had not the ammonia been applied.

From the practical standpoint, the prevention of injury from acid in pine seed beds by the use of neutralizing agents at this nursery is not a success, because beds so treated are often as badly infested by parasites as beds which have received no disinfectant treatment. The action of heavy applications of lime on the beds is also somewhat in question. Amounts up to 0.5 ounce per square foot, as used in the neutralizing work, have, however, been used alone without any bad effect. In one case 0.73 ounce per square foot (equivalent to 1 ton per acre) used on jack-pine beds at or before seeding in two different series was followed by a serious decrease of germination, and in the other case by a marked increase in the number dying after the seedlings came up. Whether the effect was a direct injury to the seedlings or a stimulation of the parasites which attack them was not determined.

The effect on weeds of acid followed by lime is also shown in Table V. Much injury to weeds occurred despite the neutralization several days later of two-fifths of the acid applied. However, it is quite certain, especially in the case of series 504, plat E, that much more injury would have occurred had not the lime been applied. Three-fourths as much acid applied to another plat in this series at about the same time, and not followed by lime, prevented the growth of angiosperms on the plat. The extremely rapid growth of the weeds on the acid-lime plats a few weeks after the application of the lime indicates that most of the remaining acid had been broken down by the lime. If enough lime had been used to neutralize one-half or three-fifths of the acid applied, it is entirely probable that all of the acid remaining at the time of the lime application would have been broken down and the soil rendered entirely safe for sowing any crop plant desired. Because the lime applied was not sufficient to take up at once all the acid remaining in the soil at the time of application, as indicated by the injury to the pines in series 507, plats M and O, the question as to whether the acid prevented weed growth largely by killing dormant seed or entirely by killing germinating seed, as with the pines, remains undecided.

Ammonia, 0.469 ounce per square foot, was used in 3 pints of water a few days after the application of 0.750 ounce of acid, with watering sufficient to prevent injury to jack pine even on unneutralized acid plats. Examination approximately 45 days after the ammonia application showed an entire absence of weeds on the acid-ammonia plat, as on the acid plats, while the four checks all contained plants of grass, Mollugo, Amaranthus, and Portulaca. For 37 days after the ammonia was applied 0.562 ounce of acid followed by 0.5 ounce of ammonia five

days later resulted in preventing most weed growth, but not all. Ammonia alone, 0.5 ounce per square foot, had no effect on the weed stand 65 days after application.

TESTS OF MISCELLANEOUS DISINFECTANTS.

Tests were also made with disinfectants other than sulphuric acid. These are summarized in Table VI, together with enough sulphuric-acid tests to afford a basis for comparison. Because a plat can be directly compared only with the others sown at the same time, the plats are grouped by series rather than by disinfectants.

TABLE VI.—*Injury to pines and weeds by miscellaneous disinfectants.*

Plat.	Disinfectant.		Days from treatment to—		Injury to pines.	Weeds present in plats.	
	Substance used.	Per square foot.		Sow-ing.			Weed exami-nation.
		Ounces.	Solu-tion.				
			<i>Pints.</i>				
<i>Pinus divaricata</i> : ¹ 60.....	{ Copper carbo-nate (basic). Ammonia.....	{ 0.017 .275	{ 1.4			{ Germination re-duced to less than one-sixth of that in checks. Nearly all seed-lings which came up were severely injured.	
62.....	Sulphuric acid	.172	1.4	0		Injury not serious.	
64.....	do.....	.257	1.4	0		do.....	
<i>P. ponderosa</i> : ¹ 415 ²	Formalin.....	.25	2	0		Germination re-duced to less than one-quar-ter that on other plats. No death due to disinfect-ant after germi-nation.	
416 ³	do.....	{ .125 .125	{ 2 2	{ 29 0		None.	
<i>P. divaricata</i> : ¹ Series 501 (8 checks).	None.....						
J.....	Hy drochloric acid.	.188	2	0	30-31..	None.....	
C.....	Nitric acid.....	.375	3	0	30-31..	Slight or none.....	
B.....	Sulphuric acid	.125	2	0	30-31..	Slight.....	
D.....	do.....	.141	1.5	0	30-31..	Moderate to heavy.	
H.....	do.....	.188	2	0	30-31..	Moderate.....	
L.....	do.....	.25	2	0	30-31..	Very heavy.....	
<i>P. ponderosa</i> : ⁴ Series 504 (5 checks).	None.....						
L.....	Formalin ⁵	.562	3	14	43.....	None.....	
A.....	Sulphuric acid	.281	2	14	43.....	do.....	
C.....	do.....	.188	3	0	29.....	do.....	

Portulaca a n d
grass abundant;³
*Amaranthus re-
trofractus* common.
One-half or two-
thirds as many as
in checks.
Grass rare; Portu-
laca, 2 or 3 plants.
None.
Do.
A single trifoliate
legume.
None.

Mollugo, grass, and
Portulaca abund-
ant; *Amaran-
thus* and *Euphor-
bia* frequent.
Half as many as in
checks, mainly
grass.
Grass, at edge only;
Equisetum, 2
plants.
Grass, 2 plants.

¹ Watering as in ordinary nursery practice.

² Germination exceptionally rapid.

³ "Abundant" indicates usually 100 or more plants per plat; "frequent" indicates 20 or more; "common" indicates intermediate numbers. All plats measured 2 by 4 feet.

⁴ Watering very frequent.

⁵ Plats covered tightly for 3 days after treatment to prevent too early evaporation.

TABLE VI.—*Injury to pines and weeds by miscellaneous disinfectants*—Continued.

Plat.	Disinfectant.		Days from treatment to—		Injury to pines.	Weeds present in plats.	
	Substance used.	Per square foot.		Sow-ing.			Weed exami-nation.
		Ounces.	Solu-tion.				
P. divaricata: ¹ Series 508 (7 checks).	None.....		Pints.			Grass abundant; Mollugo, Portulaca, Amaranthus, and Euphorbia follow in the order named.	
N.....	Formalin ²	0.375	3	8	43-51..	None detected.	
P.....	do.....	.375	2	8			
M.....	do.....	.562	4.5	8			
A.....	do.....	.75	3	14			
D.....	do.....	.75	3	10			
G.....	do.....	.75	3	6			
H.....	do.....	1.00	8	14			
L.....	do.....	1.00	4	14	43-51..	Moderate.....	
U.....	Sulphuric acid	.25	2	9			
S.....	do.....	.375	2	9			
Series 512 ³ (5 checks).	None.....					Grass, 3 plants. None.	
K.....	Hydrochloric acid.	.25	2	10		Mollugo, common; grass, Portulaca, Amaranthus, and Euphorbia follow in the order named.	
F.....	do.....	.375	3	10		Grass, a dozen or more plants; Portulaca and Euphorbia still less abundant.	
D.....	do.....	.562	3	10	47-48..	Grass, 16 plants; Portulaca, 2; Euphorbia, 2.	
A.....	do.....	.75	4	10		Grass, 4 plants; Portulaca, 2; Mollugo, 1.	
C.....	Nitric acid.....	.75	3	10		Grass, 6 plants; Portulaca, 2.	
G.....	do.....	1.00	4	10		Grass, 4 plants; unknown, 1.	
N.....	Sulphuric acid. ⁴	.281	3	11		Grass, 3 plants.	
P.....	do.....	.375	4	11		None.	
M.....	do.....	.688	5.5	11		Do.	
J.....	do.....	.688	2	11		Do.	
Series 514 ⁵ (5 checks).	None.....					Grass abundant, followed by Mollugo, Euphorbia, Portulaca, and Amaranthus in the order named.	
F.....	Hydrochloric acid.	.75	2	13	42	Grass, 14 plants; Mollugo, 3 or 4.	
G.....	do.....	.75	4	13	42	Grass, 11 plants; Mollugo and Euphorbia, several plants around edge of plat.	
A.....	Sulphuric acid	.125	1	13	42	Heavy; $\frac{1}{2}$ affected..	
		.125	1	0			
C.....	do.....	.188	2	13	42	Heavy; $\frac{1}{2}$ affected..	
		.188	2	0			
D.....	do.....	.25	2	13	42	do.....	
		.125	2	0			

¹ Watered daily, 0.3 to 0.4 inch.² Plats covered tightly for 3 days after treatment to prevent too early evaporation.³ Watered daily; dry at surface on date of examination.⁴ This plat became extra dry at time of germination.⁵ Watered daily, 0.15 to 0.3 inch, until 3 days before germination. Surface dry at that time; watering done twice daily thereafter.

TABLE VI.—*Injury to pines and weeds by miscellaneous disinfectants—Continued.*

Plat.	Disinfectant.		Days from treatment to—		Injury to pines.	Weeds present in plats.	
	Substance used.	Per square foot.		Sow- ing.			Weed exami- nation.
		Ounces.	Solu- tion.				
P. resinosa—Con- tinued.			<i>Pints.</i>				
K.....	{ Sulphuric acid Air-slaked lime. }	{ 0.50 .25 }	{ 4 }	{ 13 8 }	{ 42 }	{ Grass, 15 to 20 plants; Euphor- bia and Portu- laca, 1 or 2 each. Same abundance as in checks, but in much less vig- orous condition.	
P.....	{ Copper acetate Air-slaked lime. }	{ .281 .25 }	{ 3 }	{ 12 8 }	{ 42 }	{ Slight or none.....	
Series 516 ¹ (2 checks).	None.....	.....	.....	.....	.....	Grass abundant, followed by Mol- lugo, Portulaca, and Euphorbia in the order named. Grass, 4 plants.	
A.....	Hydrochloric acid.....	.562	3	0	28	(²)	
C.....	Nitric acid.....	.562	3	17	45	None.....	
D.....	Sulphuric acid.....	.188	2	0	28	do.....	
F.....	do.....	.281	3	0	28	do.....	
Series 518 ³ (6 checks).	None.....	.....	.....	.....	.....	None. Grass abundant, strongly predom- inating; Mollugo, Portulaca, Ama- ranthus, and Eup- horbia follow in the order named.	
J.....	Formalin ⁴	.375	3	17	45	None.....	
K.....	do.....	.562	3	17	45	do.....	
M.....	do.....	1.00	4	17	45	do.....	
C.....	Mercuric chlo- rid.....	.063	2	17	45	do.....	
D.....	{do..... Sodium chlo- rid..... }	{ .063 .188 }	{ 2 }	{ 17 }	{ 45 }	{ Grass, 5 or 6 plants; Mollugo, 1; Amaranthus, 1. Nearly as many as in nearest checks, but larger pro- portion of grass than in check.	
A.....	{ Mercuric chlo- rid..... Air-slaked lime. }	{ .094 .094 }	{ 3 0 }	{ 17 13 }	{ 45 }	{ Grass, 4 plants; Mollugo, 1. Grass, 9 plants; Mollugo, 2. Grass, 10 or 12 plants. More grass than in P; Mollugo and Amaranthus also present.	
N.....	Zinc chlorid.....	.281	3	17	45	do.....	
G.....	Copper sul- phate.....	.188	3	17	45	Slight, or none.....	
P.....	Hydrochloric acid.....	.375	2	0	28	None.....	
F.....	Nitric acid.....	.562	3	17	45	do.....	
Q.....	Sulphuric acid.....	.125	2	0	28	do.....	

¹ Watered 0.3 inch twice daily.² A little at a margin missed in watering.³ Watered 0.3 inch, usually twice daily; surface of plats never allowed to become dry.⁴ Plats covered tightly for 3 days after treatment to prevent too early evaporation.

TABLE VI.—*Injury to pines and weeds by miscellaneous disinfectants—Continued,*

Plat.	Disinfectant.		Days from treatment to—		Injury to pines.	Weeds present in plats.
	Substance used.	Per square foot.	Sow-ing.	Weed exami-nation.		
		Ounces.					Solu-tion.
P. divaricata: ¹ Series 519 (6 checks).	None.....		Pints.			Mollugo very abundant, fol-lowed by grass, Amaranthus, Portulaca, and Euphorbia in the order named.
F.....	Ammonia ²	0.5	2	34	66	Record lost.....
U.....	Mercuric chlo-rid.	.063	2	0	32	(³) As in checks. None.
V.....	{ do..... Sodium chlo-rid.	{ .063 .188	2	0	32	All seed killed.... Do.
R.....	Lime-sulphur	.313	2	0	32	Three-fourths of the seed killed by unknown factor. Records lost.
S.....	do.....	.75	2	0	32	Germination good. None.
L.....	Ferrous sul-phate.	.5	2	0	32	Record lost..... Nearly as many as in checks.
K.....	Cupric sul-phate.	.281	3	34	66	Moderate to heavy: Do.
P.....	Hydrochloric acid.	.562	3	0	32	Very heavy..... Grass, very few plants at edge of plat.
M.....	Nitric acid.....	1.125	3	34	66	Record lost..... Do.
O.....	{ do..... Sulphuric acid	{ .188 .125	1 1	34 0	32	Very slight..... Do.
C.....	do.....	.25	2	34	66	Record lost..... Grass and Mollugo, each 7 or 8 plants; Amaranthus, 1.
D.....	do.....	.25	3	34	66	do..... Grass, 3 plants.
A.....	do.....	.375	3	34	66	do..... Grass, 7 or 8 plants.
H.....	Heat, 80° C. or greater for not less than 10 minutes.	(⁴)		Few	32	None..... Grass, 7 or 8 plants; Portulaca, 1 or 2.
G.....	do.....	(⁵)		Few	32	do..... Same as for H.

¹ Watered 0.3 inch, twice daily.² Plats covered tightly for 3 days after treatment to prevent too early evaporation.³ Nearly all seed killed; heavy injury to those which germinated.⁴ Upper 2½ inches of soil heated.⁵ Upper 6 inches of soil heated.

DISCUSSION OF MISCELLANEOUS DISINFECTANTS.

HYDROCHLORIC AND NITRIC ACIDS.

Hydrochloric and nitric acids were used in series 501, plats C and J; 512, plats A, C, D, F, G, and K; 514, plats F and G; 516, plats A and C; 518, plats F and P; and 519, plats M, O, and P (Table VI). Injury by them seems to take place in just the same way as that caused by sulphuric acid, and the injured seedlings presented the same appearance as those injured by sulphuric acid. (See Pl. I, figs. 2 and 3.) Pine seeds were not killed by the amounts used at sowing, but the apices of the radicles in some plats were killed by the acid residue in the surface soil after germination began. Injury may be prevented, as with sulphuric acid, by waterings sufficiently frequent to prevent the concentration of the acid in the surface soil.

Volume for volume, the hydrochloric and nitric acids used did not seem to differ greatly in their effect on the pine seedlings or weeds, the hydrochloric acid appearing rather the more dangerous. The tests offer little opportunity for direct comparison. As with sulphuric acid, pines were less injured than weeds, and the grasses present seemed more resistant than the dicotyledons. The difference in the effect on jack pine, grasses, and *Mollugo verticillata* shows especially well in series 512 and 519, in whose checks *Mollugo* was the most common weed.

The tests show clearly the low toxicity of these acids in this soil as compared with sulphuric acid, volume for volume. Comparison of plats C and J of series 501 with plats B, D, and H in the same series indicates that sulphuric acid is three or more times as dangerous to both pines and weeds as nitric acid and much more dangerous than hydrochloric acid. In series 512, sulphuric acid seems two or three times as active against the pines as the other two acids, while the disparity in the action on weeds appears still greater. In series 516, results in plats A and D treated at the same time indicate that sulphuric and hydrochloric acids are equally toxic to the weeds when the amount of hydrochloric acid used is three times the amount of sulphuric. In series 518, plats P and Q, 0.375 ounce of hydrochloric acid per square foot appeared considerably more active against weeds than 0.125 ounce of sulphuric acid used on the adjacent plat. Weight for weight, the disparity between the two acids is much less. While the strengths of the acids used were not determined, a statement of the amounts used indicating relative concentrations of ionic hydrogen would have further decreased and might have entirely obliterated the apparent disparity in action between the three acids, as was found by Kahlenberg,¹ True,² and Heald³ in their work with these acids in water culture. For instance, using for comparison sulphuric acid containing 90 per cent H_2SO_4 and making no allowance for impurities, nitric acid containing 60 per cent HNO_3 would contain, volume for volume, but 43 per cent as much ionic hydrogen, and 30 per cent hydrochloric acid but 31 per cent as much, assuming equally complete dissociation in the dilute solutions of the three acids.

TOXIC SALTS.

Copper sulphate, tested only twice, gave rather contradictory results. In series 518, plat G (Table VI), 0.188 ounce per square foot 17 days before sowing caused little or no injury to pines and consid-

¹ Kahlenberg, Louis, and True, R. H. On the toxic action of dissolved salts and their electrolytic dissociation. *In Bot. Gaz.*, v. 22, no. 2, p. 81-124, 1896.

² True, R. H. The toxic action of a series of acids and of their sodium salts on *Lupinus albus*. *In Amer. Jour. Sci.*, ser. 4, v. 9, no. 51, p. 183-192, 1900.

³ Heald, F. D. On the toxic effect of dilute solutions of acids and salts upon plants. *In Bot. Gaz.*, v. 22, no. 2, 1896, p. 130.

erable injury to weeds, while in series 519, plat K, an amount 50 per cent greater, 34 days before sowing, with more frequent watering, caused considerable injury to pines and had little effect on weeds. Copper sulphate injured pines just as did the acids, by stopping elongation of the radicles shortly after they emerged from the seed. Recovery took place in many cases. A marked case of the production of laterals in recovery from copper-sulphate injury is seen in a seedling taken by Dr. T. C. Merrill from a bed in a similar soil at Garden City, Kans., which had been treated heavily with copper sulphate at sowing and again after germination (fig. 2). Normal yellow pine at this age should have a single straight taproot going down at least five times as far as the one figured and with relatively little development of laterals. Ferrous sulphate (series 519, plat L) gave little evidence of toxic action in the soil as compared with other substances used. Further tests are necessary to give comparable data as to the behavior of copper acetate in the soil and the effect of lime in preventing injury by copper salts, the test made (series 514, plat P) being insufficient. The results in series 518, plat N, indicate that zinc chlorid is as dangerous to weed roots in this soil as copper sulphate, or slightly less dangerous.

Mercuric chlorid in the amounts used acts differently from any of the substances previously mentioned, in that it kills dormant pine seed in the soil at Halsey at the time of application. In series 519, plat V (Table VI), the seeds which failed to germinate were taken out of the soil and carefully examined, both with a hand lens and with a compound microscope. No indication was found that they had ever commenced germination. The difference is presumably due to greater penetrative power. Mercuric chlorid in the soil is injurious both to the roots of seedling pines and to weeds in quantities, which in the case of the other salts tested would have no effect. The addition of common salt to the mercuric chlorid at the time of application appears to increase the damage it does in the soil, possibly by delaying the entire breaking down of the disinfectant until it has time to act on the plants. (Compare 518-C and 519-U with 518-D and 519-V.) The additional toxic effect could hardly have been directly due to the 0.188 ounce of common salt per square foot applied, since 0.2 ounce of salt per square foot applied dry to a jack-pine bed three or four days before sowing in an earlier series had no effect on the pines or on the grass and *Mollugo* common in the series. The addition of sodium chlorid also makes the disinfectant more convenient to work with by greatly increasing the rapidity of solution. The addition to series 518, plat A, of an amount of air-slaked lime equal in weight to the mercuric chlorid applied four days earlier prevented most of the injury to weeds which occurred with smaller amounts of the chlorid in plats not limed.

With these salts, as with the acids, the pines appeared on the whole more resistant to toxic action than the angiosperms present. There was less evidence in the experiments of a difference in susceptibility to salts in general between the grasses and the dicotyledons. Heald's tests of the resistance of corn and peas to copper salts¹ showed for these plants a reversal of their relative resistance to acid, the peas being able to grow in twice as strong copper solution as corn, whereas with four mineral acids they could grow in solutions only one-fourth as strong.

Ammoniacal copper carbonate was also used with jack pine. A plat of this pine was given a solution made up of 0.006 ounce of copper carbonate and 0.099 fluid ounce of ammonia per square foot the first day after germination, and this was repeated two days later. Eight days after germination the plat was again treated, using 0.014 ounce of carbonate and 0.22 ounce of ammonia per square foot. Practically all the seedlings were killed by these treatments. Most of the injury appeared to be done by the first two applications, in which a total of 0.012 ounce of carbonate per square foot was applied. This plat, which received a total of 0.026 ounce of copper carbonate, was resown 16 days after the last application. No serious injury occurred to the second sowing.

Another plat treated just before sowing (plat 60, Table VI) further indicated a very great toxicity for ammoniacal copper carbonate if only the amount of copper contained is considered. The injury to pine in this plat was much more severe than in plat 64, which had been treated with sulphuric acid more than 25 times the weight of the copper carbonate used on plat 60. It is probable that the extremely toxic action of this fungicide was due more to the action of the ammonia than to the copper. The known tendency of ammonia to prevent the precipitation of copper salts from solution may, however, result in more prolonged activity of the copper in this disinfectant than when simple aqueous solutions of copper salts are applied to the soil.

FORMALIN.

Like mercuric chlorid, formalin is capable of killing seed outright if applied at the time of sowing. In a test of yellow pine in which the disinfectant was applied at sowing (plat 415, Table VI) most of the seeds were killed before they gave any outward evidence of commencing to germinate. So far as could be learned, those which were able to start germination were uninjured. In plat 416 (Table VI), which received the same amount of formalin, half at the time of sowing and half at an interval of a month earlier, no injury could be detected. In all other cases, formalin was applied several days

¹ Heald, F. D. Op. cit., p. 152.

before sowing and did no perceptible damage to pines or pine seed. This was true even in series 508, plat G, in which 0.75 fluid ounce per square foot was applied six days before sowing and evaporation allowed for only three days before sowing. The effect of formalin on the weed stand seemed approximately equivalent to that obtained with one-half or one-third the volume of sulphuric acid. As the weight of H_2SO_4 per fluid ounce of acid used was at least four times as great as the weight of $HCHO$ in the formalin, the formaldehyde appears rather more effective, weight for weight, in keeping down weeds. The radical difference in the type of action of the formalin against the pines renders impossible any direct comparison with acid.

LIME-SULPHUR SOLUTION.

The results in series 519, plats R and S (Table VI), are contradictory. Injury to pines from fairly heavy applications of lime-sulphur at the time of sowing can probably be prevented by sufficient watering during the germination period. The injury to weeds occurred despite heavy watering.

EXPERIMENTS AT MORRISVILLE, PA.

During the season of 1912, in pursuance of recommendations by the writer, tests with sulphuric acid were conducted by Mr. R. E. Lee, under the direction of Mr. John Foley, forester of the Pennsylvania Railroad, at the nursery near Morrisville, Pa. Sulphuric acid only was used. All treatments tested resulted in a decreased stand. The results of very weak treatments on beds given ordinary nursery watering are shown in Table VII.

TABLE VII.—*Evidence of injury to pines by sulphuric acid applied at the time of sowing, Morrisville, Pa.*

Plat.	Number of plats averaged.	Species.	Sowing to germination.	Acid per square foot.	Watering.	Final stand, taking average of checks as 100.	Decrease in stand apparently due to acid.
			<i>Days.</i>	<i>Fluid oz.</i>			<i>Per cent.</i>
Series 631..	1	Pinus ponderosa....	6 to 9	0.031	Only as in ordinary nursery practice.	91	9
	11	do.....	6 to 9	.042		95	5
	8	do.....	6 to 9	.083		90	10
Series 632..	16	Pinus resinosa....	9 to 10	.083		55	45
Series 633..	21	Pinus strobus.....	16 to 21	.083		27	73
Series 634..	7	Pinus sylvestris....	7	.083		74	26
Series 635..	17	do.....	9 to 12	.083		63	37
Series 636..	7	Picea excelsa.....	11	.083		56	44
Series 637..	14	Pinus sylvestris....	8 to 10	.083		62	38
Series 638:							
A.....	1	do.....		.188	0.15 inch, twice daily.	34	66
D.....	1	do.....		.25		26	74
C.....	1	do.....		.375		4	96
G.....	1	do.....		.188		83	17
F.....	1	do.....		.25		53	47
J.....	1	do.....		.375		45	55

The relative resistance of *Pinus ponderosa* to the acid is probably due to its rapid growth, as at Halsey. The severe injury to *P. strobus* is rather surprising in view of the length of time which elapsed before germination. The consistent relation in series 638 between the decrease in stand and the amount of acid used and the evidently helpful effect of frequent watering leave no reasonable doubt as to the agency of the acid in causing the decreased stand. In all of the series except 631 the treated plats were uniformly poorer than the checks. In series 638, fewer seedlings appeared in acid plats than in the checks in all cases, the deficiency being greatest in the ordinary watering plats, and the amount of death just after the seedlings came up in the ordinary watering plats was very large. The amount of germination and early loss for the other series was not determined.

The evidence of the experiments at Morrisville as a whole shows that at this nursery the amounts of acid necessary to cause injury were much smaller than at Halsey.

GENERAL DISCUSSION AND CONCLUSION.

It is evident that the toxicity of disinfectants to the roots of plants in soil at Halsey, Nebr., varies greatly in response to a number of different factors. The amounts of water in different parts of the soil at different times and the movements of soil water, which result in concentrating the soil solution at particular points, must be considered, as well as the concentration of the solution applied. The depth of the root tips in the soil at the time of greatest concentration of the soil solution is also of prime importance, and the time of application is a very important variable.

In general, while it is evident that disinfectants do not act on plant roots in soil to the same extent as in liquid cultures, they seem to act in much the same way. If only the free poison in the soil solution is considered, it is doubtful whether a great difference in degree of toxicity can be found in soil and in liquid cultures. However, the activity of poisons in the soil solution should not be expected to equal their activity in pure water cultures. Antitoxic relations which have been found by various workers to exist between numerous substances in water cultures may be expected to exist between most disinfectants and various components of the soil solution. An investigation of antagonism between substances obtained in soil extracts and some of the substances used in soil disinfection should yield some interesting results. Most poisons are of necessity rather unstable substances, and even where leaching is prevented, as in pot experiments, and nonvolatile substances are used, the loss of free poisons from the soil solution by combination with soil constituents and by other absorptive processes is undoubtedly great.

That acid solutions, in fact, are much more toxic just after application is clearly shown by the experiments at Halsey. That the rapidity with which disinfectants are rendered inactive in the soil should vary greatly in different soils is to be expected, in view of the great differences which exist in both their physical and chemical constitution. However, examinations of soils by the usual methods of chemical and physical analyses and lime requirement and wilting-coefficient determination do not give much indication as to how sulphuric acid may be expected to behave in different soils. A soil with a low wilting coefficient may be expected to have a rather low average water content under field conditions and therefore to require small amounts of disinfectants to raise the soil solution to a killing concentration. Coarse texture indicates low absorptive power and a consequent small capacity for disinfectants without injury to roots. A high lime requirement may indicate soil acidity, but it may also be found in a nonacid soil which has high absorptive capacity.¹ Both on theoretical grounds and from the results obtained at Halsey with sulphuric acid and mercuric chlorid treatments followed by lime, the carbonates present should have a decided influence in preventing injury by acids, and probably by many toxic salts as well. Experiments are under way at several nurseries at which preliminary results indicated a distinct relation between determinable chemical and physical characters and the behavior of disinfectants. But between soils as much alike as those on which the foregoing experiments were conducted, the physical and chemical examination made gives no clue to any difference which can explain the different behavior of sulphuric acid on the two. Neither soil yielded CO_2 by the method employed in the examination by the Bureau of Soils. The surface soil at Morrisville contains more CaO , has a higher ignition loss, a higher wilting coefficient, and a lower lime requirement than the Halsey soil, all of which would seem to indicate a greater capacity for acid at Morrisville. The experiments show throughout that the reverse is the case. While the tests made at the two nurseries are not absolutely comparable, comparison of the plats of series 501 (Table VI), which received from 0.125 to 0.25 ounce per square foot, with series 631 to 637 inclusive (Table VII), in which from 0.031 to 0.083 ounce was used, indicates that at Halsey the amount of acid required to cause injury is three times that required at Morrisville. It seems probable, in view of the semiarid conditions at Halsey, that the Morrisville soil was more acid or less alkaline than the Halsey soil.

An attempt to get an indication of different reaction between the two soils a year after the samples were taken failed, both soils giving

¹ Cameron, F. K. The Soil Solution, the Nutrient Medium for Plant Growth, p. 65, footnote 1. Easton, Pa., 1911.

negative results with the potassium nitrate and iodine test outlined by Loew¹ and turning blue litmus red, the latter phenomenon likely indicating absorption rather than acid reaction for either soil.² Titration of extracts from fresh samples of these soils should give more indication of the real cause of the different behavior of acid at the two places. If difference in reaction of the two soils explains the different results, it is probable that the difference in capacity for disinfectants would be less marked or even reversed with such disinfectants as copper sulphate.

Further evidence of the failure of chemical analysis or physical characters to show what action disinfectants will have on roots in different soils is seen in the difference between the results in these nursery soils and the results obtained by Lipman and Wilson³ with a soil described as sandy and having a chemical constitution showing no very radical differences from those reported in the foregoing. On this soil they found that there was no evidence of damage to either wheat or vetch seedlings by sulphuric acid in the amount of 600 parts per million of water-free soil applied several days before sowing. While these experiments, conducted in pots, can not be directly compared with those of the writer, it is sufficiently evident that the results are very different. At Halsey, 0.125 fluid ounce per square foot, followed by the ordinary watering given germinating seed beds, entirely prevented the growth for at least a month after application of the monocotyledonous and dicotyledonous weeds represented in the seed beds. Assigning to the commercial acid used a maximum strength, which may be assumed as having a specific gravity of 1.84 and purity of 95 per cent, and to the soil a minimum weight, which for this fine sand may be taken as 80 pounds per cubic foot, we find that even if all the acid applied were held in the upper 4 inches of soil the weight of H_2SO_4 used was only 534 parts per million of soil. That this treatment should have prevented all growth of weeds, in which both monocotyledons and dicotyledons were represented, while 600 parts did not even decrease the growth rate of wheat and vetch on the soil used by Lipman and Wilson, indicates a very considerable difference in behavior of acid in the two soils. As injury to pines is caused on the Morrisville soil by amounts of acid only one-third of that required to injure pines at Halsey, the contrast in the results between the Morrisville soil and that used by Lipman and Wilson is still more marked.

The observations made by the writer on the species of *Equisetum*, pines, grasses, and dicotyledons most common in the seed beds at

¹ Loew, Oscar. Studies on acid soils of Porto Rico. Porto Rico Agr. Exp. Sta. Bul. 13, p. 6, 1913.

² Cameron, F. K. Op. cit., p. 66.

³ Lipman, C. B., and Wilson, F. H. Toxic inorganic salts and acids as affecting plant growth. In Bot. Gaz., v. 55, no. 6, p. 409-420, 1913.

Halsey indicated a considerable variation in resistance to sulphuric acid between species of these four phylogenetic groups, exceeding the variation between different species in the same group. It further appeared that, for the four main groups represented, the higher the group in the evolutionary scale the greater the susceptibility of its representatives to injury, not only by sulphuric acid but by hydrochloric and nitric acids and by some of the toxic salts. It is understood, of course, that these differences would not be expected to obtain with all species of these groups, and parallel water-culture tests with the species observed by the writer would probably show that some of the differences in susceptibility indicated in the nursery tests were due to other factors than variable protoplasmic resistance. The experiments reported in the foregoing were devised primarily for developing disease-control methods, and interpretation of many of the direct effects on the seedlings is of necessity difficult.

From the practical standpoint, it seems probable that sulphuric acid can not be used alone as a disinfectant for sandy soil soon to be sown with truck crops. This is at least true if the plants to be grown prove as susceptible to acid injury as the dicotyledonous weeds encountered in these experiments seemed to be. However, acid can probably be applied with safety on most soils several days before sowing if air-slaked lime sufficient to counteract three-fifths or more of the acid used is raked into the surface soil just before seed sowing. Sulphuric acid is so much cheaper than formalin that if subsequent lime neutralization is found practicable this acid may in many cases supplant both heat and formaldehyde as a soil disinfectant for work in which immediate reinfection with parasites is not feared. The writer's experience indicates that, aside from the destruction of parasites, soil treatment with acid followed by lime results in a considerable increase in the growth of many plants, in some cases being more prompt and marked than that following heat disinfection.

SUMMARY.

Sulphuric, hydrochloric, and nitric acids, and copper sulphate used in disinfection of seed-bed soil caused injury to the roots of pine seedlings and prevented the development of many species of angiospermous weeds. All cause injury to pines by killing the growing apex of the radicle immediately after the seed germinates. They can be used to disinfect pine seed beds only if the operator knows how to recognize and prevent such injury to the pines. Typical healthy and acid-injured seedlings are shown in Plate I, figures 1, 2, and 3, and a method by which injured seedlings can be distinguished from others is described on page 9. Many injured seedlings later resume root growth and recover (Pl. I, fig. 4, and text figs. 1 and 2). Injury is due to the concentration of the disinfectant in the surface soil

consequent on the capillary rise of the soil solution and the evaporation of water from the soil surface. It is found that in a sandy Nebraska soil all injury can be prevented by very frequent watering during the germinating period (pp. 11-12). It can also be prevented in the case of acid applications by adding lime to the soil shortly after treating with the disinfectant (pp. 21-22). The lime method, while undesirable in the case of pines, is probably the only one which will prevent injury to angiospermous seedlings. The acids can be applied to seed beds at the time of sowing without any injury to dormant pine seed. Formaldehyde and mercuric chlorid in sufficient disinfecting strengths must be used several days before seed sowing, as they are able to kill dormant pine seed in the soil. Formaldehyde applied at or before seed sowing never causes the injury to germinating pines that is caused by the acids and salts.

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(PROFESSIONAL PAPER.)

OBSERVATIONS ON THE PATHOLOGY OF THE JACK PINE.

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INTRODUCTION.

A discussion of the fungous diseases of a particular forest tree is incomplete unless the general habitat in which the tree grows and which influences the occurrence and virulence of its diseases is considered. In general, a description of the characteristic home of the jack pine (*Pinus divaricata* (Ait.) Du Mont. de Cours.) is essentially that of the sandy plains in the region of the Great Lakes, where it attains its greatest size. Here the sand deposits are usually of great thickness and heavily mixed with glacial drift. The soil is composed chiefly of the same materials. With the exception of some of the lower plains and old lake levels the humus soil is very thin. In most regions within the range of the jack pine there is practically no humus. Where humus does exist in any appreciable thickness it is so much a part of the underlying sand and gravel that it dries out very rapidly, affording no opportunity for a luxuriant and uniform forest cover. Exceptions to this occur in parts of Minnesota and Canada. The improvement in the quality of the soil is at once reflected by the larger size of the jack pine and incidentally in the nature and virulence of the diseases attacking it. Observations show that a continuous and sustained growth in the case of the jack pine is not conducive to much injury from wood-destroying fungi.

Owing to the rapidity with which the soil of the jack-pine "plains" dries out and to the inflammable nature of the slight ground cover, favorable conditions are furnished for forest fires. This, in turn, likewise greatly influences the presence of fungous diseases as a result of injuries caused by the fires. Severe and rapid changes in temperature and a fluctuation of the mean annual precipitation are other factors characteristic of the jack-pine habitat. The susceptibility of forest trees, and likewise of the fungi attacking them, to the influence of soil and climate directly or indirectly produces conditions favor-

able or unfavorable to the best development and spread of disease. The fungi inhabiting the bark and leaves are probably influenced by these factors in a far greater degree than are those attacking the heartwood.

Pathologically, the jack pine may be divided, in most regions of its range, into two forest types, which are determined largely by the amount of moisture in the soil.

The fungi at work in the moist or swamp type may occur in the drier and more arid type, but may show considerable variation in the abundance of any one species. Another factor of considerable importance is the absence or presence of any associate tree of the type which may prove equally or even more susceptible to cosmopolitan fungi and thus increase the chances of infection for all members of the stand. In many parts of its range the jack pine occurs in pure stands. In mixture with other species it is usually attacked by a greater number of diseases than in pure stands.

DISEASES.

The fungus causing the greatest immediate injury to the jack pine of all age classes, as determined by pathological surveys in Michigan and Minnesota, is *Peridermium cerebrum* Peck (*Cronartium quercus* (Brondeau) Schrot.).¹ The galls (fig. 1) produced through the stimulative effect of the fungus are in May and June covered with globoid swellings somewhat after the manner of the convolutions of the



FIG. 1.—An 18-year-old jack pine infected with *Peridermium cerebrum*, showing the characteristic swellings which extend around the main stem.

¹ *Peridermium cerebrum* is quite similar to *P. harknessii* Moore, which causes much damage to *Pinus contorta* (lodgepole pine) in the West. Some recent observations by Hedgcock and Meinecke indicate the possible identity of *Peridermium cerebrum* with *P. harknessii* on *Pinus radiata* (Phytopathology, vol. 3, p. 16, 1913). These two *Peridermium*s are held by Arthur and Kern to be identical (Mycologia, vol. 6, no. 3, pp. 133-137, 1914). Cultural experiments by Arthur and Kern (Mycologia, vol. 6, no. 3, pp. 133-137, 1914) and also by Hedgcock and Long (Journal of Agricultural Research, vol. 2, pp. 247-249, 1914) demonstrate the identity of *Peridermium fusiforme* with *P. cerebrum*. *Peridermium globosum* Arthur and Kern founded on a single specimen and supposed to occur on *Pinus strobus* has been acknowledged by the authors to be *P. cerebrum* on *Pinus divaricata*. The error arose from a misidentification of the host (Mycologia, vol. 6, no. 3, pp. 133-137, 1914).

brain—cerebroid. These blisterlike swellings are orange-yellow at first; after the rupture of the peridium and the dispersal of the golden yellow æciospores they become whitish. The gall formation causes great injury to the trunk and branches (fig. 1). The infection usually begins by means of some injury to the bark or cambial layer.¹ The gall swellings gradually increase from year to year from the growth of a perennial mycelium, so that they finally encompass the entire branch, resulting eventually, if the galls are near the trunk, in its death below and above the hypertrophy. Whether or not the entire branch dies depends upon the presence of lateral, leafed branches below the gall.

In dry sandy areas *Peridermium cerebrium* confines itself more generally to the branches, occurring rarely on the trunk but frequently in the axils of the branches. This latter condition usually results in a combination trunk and branch gall, which in numerous instances produces greater damage than either of the other two types of galls. The branch and trunk are girdled by a bnormal wood tissue and are thus weakened (fig. 2). This results usually in either the branch or the tree being blown down by the wind. Personal observations show that borers and wood-rotting fungi entering at the burl often hasten the decline of the tree.

From a careful examination of young twigs showing very recent infections at leaf scales, leaf traces, and at the bases of young pistillate



FIG. 2.—Cross sections of the main trunk of a jack pine heavily infected with *Peridermium cerebrium*. Note the progressive girdling by the resinous burl tissues in the upper figure and its effects on the increment of the trunk below, as shown in the lower figure.

¹ Wounds made by sapsuckers, ovipositors of bark-stinging insects, rodents, and ice and snow breaks are common means of entrance for *Peridermium cerebrium*.

flowers, it is believed that *Peridermium cerebrum* can enter young seedlings or the tender portions of more mature growth without first having the bark broken. Entrance in this manner must, out of necessity, be aided by sufficient moisture for germination and to permit a rapid penetration by the young mycelium. On the sandy plains of the Great Lakes region rain water disappears almost immediately and the sand becomes heated about the isolated tree groups, causing a rapid evaporation from the surface of the trunk and branches and leaving the moisture content of the outer bark at a minimum. In whatever manner the fungus may enter its host, directly or through wounds, the number of galls and imperfect branches is usually much less on trees of the sandy barrens than in more moist regions.

In swampy areas the jack pine grows in close stands. Here the percentage of infected trees is much greater. The trunks of the 6 to 12 year old jack pines are often covered with swellings stunting the growth of the trees very rapidly (Pl. I, fig. 1). Trees so infected never reach maturity and may continue living for an indefinite period in a stunted condition, to be finally blown over by the wind or broken down by the snow. The 1 to 4 year old seedlings are quite often attacked. With these, as is often the case with larger trees which through mechanical injury may become infected at the ground, the gall is formed directly at the base of the main stem. When a seedling is infected there or higher up on the stem, it develops into a deformed growth after the manner of a witches'-broom (Pl. I, fig. 2) and never attains a height of more than 2 or 3 feet. The perennial mycelium of the fungus thrives in the cambial layer and in the living parts of the sapwood. Trees with a single infection on the trunk occurring at the age of 4 to 6 years are known to support the living mycelium of the fungus to the advanced age of 70 to 80 years. Usually, however, the excessive production of resin in the infected tissues infiltrates the woody portion of the trunk, and the sap supply is cut off so that death results in a comparatively short time (fig. 2). This is especially true in young seedlings. *Peridermium* galls are frequently observed a foot or more in diameter. Trees supporting galls of this size had succumbed in every instance to the disease.

Some knowledge of the damage done by *Peridermium cerebrum* to the jack pine may be obtained from notes of a pathological survey by the writer in the national forests of Michigan. Out of 100 trees of an average plat on dry sandy soil, not selected because of any pronounced diseased condition, 50 per cent were heavily infected, while only an occasional tree out of a second hundred on similar but moister soil was absolutely free from the disease. Out of 100 trees taken from the swamp type, practically all were infected. Not all the trees were infected seriously. A tree bearing a single branch gall



FIG. 1.—A 6-YEAR-OLD JACK PINE INFECTED WITH PERIDERMUM CEREBRUM.

The complete girdling of the main stem by two oppositely arranged galls is shown. Note the wedge-shaped gall tissues.

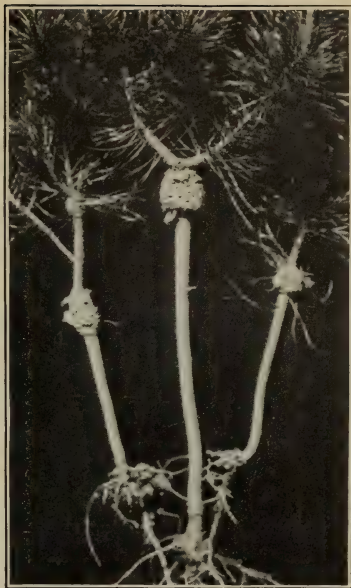


FIG. 2.—FOUR-YEAR-OLD SEEDLINGS OF JACK PINE, SHOWING THE CHARACTERISTIC SWELLINGS OF PERIDERMUM CEREBRUM.

The entire crown of the seedlings develops into spherical brooms.



FIG. 3.—VARIOUS TYPES OF INFECTION OF YOUNG JACK PINE BY PERIDERMUM COMPTONIAE.

Note that in the central figure the fungus has invaded the underground tissues of the stem.

was marked "infected." Four trees specifically studied yielded by actual count an average of 220 burls on the branches and 13 on the trunks. The cones produced by these trees, although of average number, were small, with a higher percentage of abortive sporophylls than is commonly the case with this species (fig. 3). Comparative germination tests of seeds from heavily infected and vigorous non-infected jack pine of the same age and type conditions showed for the former a germination of 19 per cent below that of the latter. For this experiment 10 samples, consisting of a dozen or more cones, were taken from each of five heavily infected and five uninfected pines. Fifty seeds from each of these samples were planted in sand, kept moist with distilled water, and allowed to stand at laboratory temperature (about 70° F.) for 90 days.

The prolific development of *Peridermium cerebrum* in many parts of the jack-pine forests of the Great Lakes region is a factor in reforestation which should be carefully considered. The fact that the fungus occurs so commonly



FIG. 3.—Branch of jack pine with aborted cones, the result of a severe attack of *Peridermium cerebrum*. Note that some of the cones did not open and that most of them are less than an inch in length. Average normal cones measure from 1½ to 2 inches.

on young seedlings in the natural forest and occasionally in the nursery shows that it is a menace to the best development of the species. The largest and best formed jack pine in all the regions studied where the *Peridermium* was abundant was almost entirely devoid of this injurious disease. However this may be interpreted as to the original differences in vigor, the fact that heavily infected trees were invariably scrubby and ill formed is, in the mind of the writer, directly referable to the effects of the parasite. The fact that *P. cerebrum* has its telial stage on the leaves of several

species of *Quercus*¹ should be of much significance in control work. *Quercus velutina* and *Q. coccinea* are two scrub oaks frequently forming a conspicuous part of the jack-pine type, particularly in Michigan. Methods could be devised for the eradication of these worthless species, thus removing the alternate host of the fungus. However impracticable this may be on a large scale, in wood lots and small holdings this would not be a very difficult matter. The removal of infected branches of young growth could be done in the orchard-like stands of jack pine on the more sandy soils, thus saving many young trees from early suppression.



FIG. 4.—Young jack pine infected with *Peridermium comptoniae*. Note the ruptured peridia with their serrate margins.

In a few instances, in the region studied, young jack pine was found to be diseased by *Peridermium comptoniae* (Arthur) Orton and Adams (*Cronartium comptoniae* Arthur). (Fig. 4.) In the experience of the writer this fungus was not common. The æcial stage of the fungus is chiefly characterized by a slight fusiform swelling, seldom forming the spherical galls so characteristic for *P. cerebrum*. The peridia rupture with a sharply serrate or spiny margin. The fungus is further distinguished from *P. cerebrum* by attacking principally young seedlings (Pl. I, fig. 3) and causing excessive brooming of the branches. It was not found on more mature growth. *P. cerebrum* attacks both young and old trees. *P. comptoniae* has its alternate stage on sweet fern² (*Comptonia peregrina* and *Myrica gale*). Without the production of the teliospores on these plants the fungus can not reproduce itself on the jack pine.

As a precaution against these *Peridermiums* entering the forest nursery and the possibility of their transportation to other regions, all alternate hosts, such as species of oaks and sweet ferns, should be removed from the vicinity of the nursery. This immunity zone should be extended as far back from the nursery as time and means will allow. Before new nurseries are established a pathological survey of the immediate region should be made as to the presence of these heteræcious pine rusts. Much attention should also be given

¹ Demonstrated by Dr. C. L. Shear, Jour. Myc., vol. 12, p. 89, 1906.

² Demonstrated by G. P. Clinton, Conn. Agr. Exp. Sta. Rept., 1907, pp. 380-383, 1908.

the selection of nursery sites, with regard to the topography and prevailing winds of the region.

With the exception of *Peridermium cerebrum* and *P. comptoniae*, few fungi of economic importance attack the living jack pine in the drier parts of its range. On the dry pine barrens of the Lake States the jack pine reaches its normal age without much defect in the wood arising from fungous diseases, although exceptionally old trees of 90 years and more frequently show considerable decay. In mixture with other species in the more moist regions of its range, particularly in parts of northern Minnesota and of Canada, *Trametes pini* (Brot.) Fr. causes considerable heart-rot in trees of 60 years and older. In general, however, this fungus is in negligible quantities. In close stands jack pine prunes readily during its most rapid growing period, forming straight clear stems. The rapid occlusion of the branch knots shortens the danger period for infection by wound fungi. It is principally due to this fact that some of the most serious wood-destroying fungi do not effect an entrance until the tree has reached its period of decline.

Polyporus schweinitzii Fr., causing a butt rot, is usually in greater abundance than *Trametes pini*, but the percentage of infected trees, even on the more protected soils, is seldom more than 2 to 4 per cent of the stand. The jack pine is a deep-rooted species and unless the root system comes in contact with a hard stratum of clay and gravel, root-destroying fungi are largely a negligible quantity. In this class are *Fomes annosus* Fr. and *Armillaria mellea* (Vahl.) Quél., which very rarely occur on the jack pine. Only a few isolated and unimportant infections have ever been recorded by the writer.

The jack pine does not suffer any material injury from needle fungi. Those that do occur are mostly of a saprophytic nature. *Lophodermium pinastri* Schrad. is found only occasionally.

On dry soils in open stands the jack pine frequently shows a tendency to form witches'-brooms. The terminal shoot, which is the part usually affected, develops into a thick-matted broom, precluding any further growth in that direction. Trees thus infected usually show a rapid falling off in increment, probably dating from the time when the influence of the parasite was first felt. Another type of broom formation is confined to the lower and older branches and has a similar effect on the growth of the host. These brooms are probably caused by some perennial fungus. In the absence of any fruiting structures the causal organism can not be determined.

The jack pine in its eastern range is not subject to mistletoe injury. Macoun¹ reports the occurrence of *Razoumofskyia americana* (Nutt.) Kuntze, the lodgepole-pine mistletoe, on the jack pine in Canada.

¹ Macoun, John. Catalogue of Canadian Plants, pt. 3, p. 422. Montreal, 1886.

The writer finds this mistletoe to be the cause of serious damage to the jack pine at its most western extension or where it approaches the zone of the lodgepole pine in the north.

SAPROPHYTIC FUNGI.

Aside from the previously mentioned wood-destroying species, which in many cases continue alive after the death of the host,¹ the usual strictly saprophytic fungi of coniferous woods are found on cut or fire-killed jack pine. *Ceratostomella pilifera* Fr., the blue-stain fungus, appears very rapidly after the death of the tree. In moist situations, species of *Auricularia* and *Dacryomyces* are surprisingly abundant, but can be of little importance, as the mycelium does not penetrate the wood to any appreciable distance. The first fungus of importance is *Polystictus abietinus* Dicks. This is a sap-rotting species and is seldom absent from fire-killed trees after the second or third year. Second in importance is *Lenzites sepiaria* Fr., which works both in the sap and in the heartwood and usually appears on the fallen trunks after they have lain for three or four years, following up the first-mentioned fungus. The *Lenzites* appearing on jack pine is invariably the true, small, thin-fruited form, with radiating gills. *Lenzites sepiaria* is as easily recognized by the orange-yellow color of its growing margin as the young, growing *Polystictus abietinus* is by its beautiful purple tinge. *Fomes pinicola* Fr. has very little to do with the decay of fallen jack pine. This fungus has not been found to be very common. *Polyporus palustris* Berk. and Curt. occasionally appears, but is more common on dead Norway pine. *Fomes carneus* "Nees" very rarely occurs on jack pine. *Lentinus lepideus* Fr., *Polyporus sulphureus* Fr., and *Trametes sepium* have been collected by the writer on dead jack pine, but they are very rare. Resupinate Thelephoraceæ occur only in the moist stands of mixed species. Those which may be considered of importance in the decay of fire-killed timber in the forest are *Corticium byssinum* (Karst.) Burt., *C. sulphureum* Pers., *C. galactinum* (Fr.) Burt., *Coniophora olivaceæ* (Fr.) Bres., and *Peniophora globifera* E. and E. A yellowish white *Poria* which goes under the name of *P. subacida* Peck is occasionally found on fallen jack pine in Minnesota. This fungus has been observed by the writer in a fruiting condition on old boxes and barrel staves made from newly felled living trees. This indicates its probable parasitism on jack pine in the living forest.

¹ This is a fact that is not generally appreciated, and on it depends the solution of some very important pathological problems in the forest. Vigorously growing sporophores of *Trametes pini* springing from original infections in the living tree have been collected from a fallen western larch which had lain on the ground for more than 100 years. This was determined by the age of a western red cedar growing astride the fallen trunk. Practically all the more serious wound and root fungi of the genera *Trametes*, *Fomes*, *Polyporus*, and *Agaricus* in moist situations continue alive indefinitely after the death of their hosts.

INJURIES DUE TO OTHER CAUSES.

In the absence of an adequate snow protection on the flat wind-swept pine barrens of the Lake States, winter injury sometimes results to young growth from long exposure to freezing temperatures. Winter-injured seedlings of jack pine, however, recover more rapidly than those of the more sensitive associate species and when in this condition are not so apt to be attacked by secondary deteriorating agents. It has already been stated that the deep root system of the jack pine is unfavorable to some root-destroying fungi. In like measure this is a safeguard against injury by wind. It is very unusual to find jack pine blown down by the wind when the trees are in a healthy condition. Very old trees sometimes succumb to strong winds, but it is found that such trees are usually mechanically weakened by wood-destroying fungi. The jack pine may be considered very windfirm. Porcupines and squirrels are known to do considerable injury to jack pine during the winter months when food is scarce. The latter animal is much addicted to gnawing the galls of *Peridermium cerebrum* in the spring during the period of the exudation from the diseased bark of a sweet yellow liquid which bears the conidiospores of the fungus. Since squirrels also gnaw the galls when the æciospores are mature, they may be considered a factor in the distribution of this fungus. The bark of the galls is frequently completely gnawed away, killing the infection.

In general, the jack pine is very sensitive to fire, which usually causes the greatest injury in the typical dry sandy jack-pine plains. In many cases fire injury in jack pine results from repeated burnings, the tree having successfully withstood the first slight ground fires. Fires in the more typical jack-pine forests pass through very quickly, so that the thickened bark immediately at the base of the tree affords sufficient protection until it is burned off by succeeding fires, which frequently occur notwithstanding the meager ground cover. The fact that the species frequently grows in orchardlike stands or in isolated groups, more or less separated from one another by free areas, greatly lessens the damage of the fire spreading from one group to another. However, the low-spreading branches, which often extend to the ground, increase the danger from crown fires.

CONCLUSIONS.

With reference to the prevalence and severity of its fungous enemies, two distinct forest types for the jack pine may be recognized: The pure dry sandy-plain type and the mixed type of moist protected soils.

The most important fungous disease of the jack pine is *Peridermium cerebrum* Peck, the control of which in many localities is quite a serious

forest problem. The fungus attacks all age classes, causing the death or early suppression of trees of tender years and seriously interfering with the propagation and development of more mature growth.

From the standpoint of merchantability, wood-destroying fungi in the living tree are in almost all regions a negligible quantity. The two most important are *Trametes pini* (Brot.) Fr. and *Polyporus schweinitzii* Fr. These, however, do not produce any appreciable decay till after the tree reaches its period of decline, which is attained after a comparatively rapid early growth. This period may be placed approximately at from 60 to 80 years.

The wood of dead jack pine rapidly deteriorates under the influence of a number of saprophytic fungi and may not be expected to remain sound in the forest for more than two or three years.

Jack pine is sensitive to heat, but suffers only occasionally from winter injury.

Because jack pine in general is comparatively free from a number of the diseases which are common on other conifers and is resistant to drought, winter injury, and frost, it is admirably suited for reforesting many of the dry sandy regions of the North-Central States.

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THE TOXICITY TO FUNGI OF VARIOUS OILS AND SALTS, PARTICULARLY THOSE USED IN WOOD PRESERVATION.¹

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INTRODUCTION.

Within comparatively recent years the subject of wood preservation has become of paramount importance, largely resulting from the economic conditions which necessitate the utilization of timber inferior in its resistance to decay to species formerly readily obtained. The rise of wood preservation in the United States within the last two decades has been very rapid. The principal preservatives used have consisted of coal-tar creosote and zinc chlorid, either alone or in combination. Such experimental work as has been done prior to the last two or three years has been directed in large part toward perfecting the mechanical processes of injecting the preservatives into wood, with an idea of securing the greatest relative efficiency as compared with the cost involved—purely an engineering proposition based on

¹ The writers wish to thank Mr. Howard F. Weiss, Director of the Forest-Products Laboratory, Madison, Wis., for the interest displayed and suggestions offered during the progress of this work, as well as for the laboratory facilities placed at their disposal. Thanks are also due to Mr. Ernest Bateman, Chemist in Forest Products at the Forest-Products Laboratory, for all the data on chemical analyses of the different preservatives, and to Drs. R. H. True, F. D. Heald, E. P. Meinecke, Caroline Rumbold, and Mr. W. H. Long, of the Bureau of Plant Industry, for many helpful criticisms of the manuscript. The investigations were conducted at the Forest-Products Laboratory, Madison, Wis., maintained by the Forest Service of the United States Department of Agriculture in cooperation with the University of Wisconsin.

NOTE.—This bulletin gives the results of a series of investigations conducted at the Forest-Products Laboratory, Madison, Wis., as to the preservative value of various oils and salts and their toxic effect on wood-destroying fungi.

economic considerations as far as the preservatives used are concerned. These preservatives have in a general way proved to be fairly good, but recently further efforts have been made to supplement them, or perhaps to substitute for them under certain conditions other substances which may be more applicable to certain requirements.

In addition to the toxicity of a preservative toward wood-destroying organisms, its value to the trade will depend largely upon its varied physical and chemical properties, as well as upon certain economic considerations involved. The present publication, however, deals only with the toxic properties. Considerable literature on the toxic effect upon plant and animal life of various chemical substances, both inorganic and organic, has accumulated, but relatively little work has been done with wood-destroying fungi, and any attempt to draw analogies would be misleading.

Even among fungi the toxic concentration of a given preservative will vary, depending upon the organism, the concentration of the preservative, and the growth conditions, such as the composition of media and the temperature. In order to call attention to the fundamental character of certain of these variations and to illustrate the points involved, a brief survey of some of the work of other investigators is here presented before the results of our own work are discussed. No attempt has been made to review all the literature on this extensive topic, and only a few references which serve to illustrate the points the writers desire to emphasize are included.

HISTORICAL.

STIMULATION BY TOXIC SUBSTANCES.

Many investigators have established the fact that certain substances that are poisonous in higher concentration exert only a stimulating effect in extreme dilution. For many years the fluorin compounds have been known to have this stimulating effect upon fermentation. Ono (22)¹ and Raulin (24) have found similar favorable influences exerted by lithium nitrate and sodium fluorid upon algæ and by mercuric chlorid and copper sulphate upon fungi. Fred (9), in his studies on nitrogen fixation, denitrification, ammonification, and putrefactive processes in soils, due to certain bacteria and yeasts, concludes that the yield is in proportion to the toxic stimuli. Likewise, Clark (3, p. 400), in his work on the toxic effect of many acids and salts upon fungi, found that many deleterious agents which at certain concentrations retard germination or early growth afterwards cause a great acceleration of mycelial development.

¹ Figures in parentheses refer to the bibliography at the end of this bulletin.

VARIATION IN TOXICITY OF CHEMICAL SUBSTANCES TO DIFFERENT FORMS OF PLANT LIFE.

A review of the literature on the action of various toxic agents shows that the different forms of plant and animal life often behave very differently toward the same chemical substance. However, on account of the complexity of the digestive and absorptive processes in the higher animals, particularly man, a direct comparison of these forms with plant life is of little value, although the economic consideration of safety in the handling of substances in commercial use is of great importance.

A few general statements to indicate in a concrete form the differences in behavior between the larger plant groups, as well as individual species, will illustrate the point which it is desired to make.

It is unfortunate that the work of different authors can not, in many instances, be directly compared, on account of differences in the method employed. However, much of value can be deduced from the few available examples.

In his valuable work, Clark (3) calls clearly to the attention the variations among different species of molds. Certain toxic agents are shown to present great differences in this respect and others only slight ones. Even the stage of development of a single organism is of great importance, the conidia of the five species used proving more sensitive than the mycelium, so that the inhibition point for spore germination can not safely be considered as the toxic point for the development of mycelium.

Other species of fungi, however, may behave differently from the ones Clark worked with, for Rumbold (25, p. 431) has recently shown that the ascospores and conidia of the blue-stain fungus (*Ceratostomella* sp.) are more resistant than the mycelium to sodium hydroxid and sodium carbonate.

Another interesting phase of the question has been studied by Pulst (23). This investigator shows that the common green mold (*Penicillium glaucum*) has the power of gradually increasing its resistance to toxic agents. He claims that the individual itself without change of generation, but after a somewhat longer period of time, works up its resistance to copper sulphate to a high degree. He also shows by experiment that spores sown from generation to generation on progressively increasing concentrations of this salt likewise attain greatly increased resistance. Similarly, this newly developed resistance is evidenced by an increased rate of growth. For instance, when spores produced on a 3.2 per cent solution of copper sulphate are transferred to new media of like concentration, the mold will fruit again in about 10 days, while spores obtained from a culture containing no toxic substance and transferred in exactly the same manner require more than three months to reach the same stage of development.

Seed plants.—A great amount of work has been done to ascertain the effect of various toxic substances on the roots of higher plants. A discussion of this work, however, is not essential to the present paper beyond showing that a considerable difference exists between the behavior of this group of plants as compared with the lower forms.

In the comparison by Harvey (11) of his own work on an alga (*Chlamydomonas multifilis*) with that of True and Hunkel (30) on a flowering plant (*Lupinus albus*), both investigators using the ortho, meta, and para compounds of dihydric phenol, cresol, and phthalic acid, the alga was found to withstand a concentration three to eight times as high as the flowering plant.

Another striking illustration of this varied response to the same toxic solution is recorded by Heald (12, p. 130), who found a fungus vigorously growing on pea roots which had been killed by hydrochloric acid. The average death point for five species of molds studied by Clark (3, p. 306) was $\frac{n}{3.3}$ HCl (1.1 per cent), while the three species of flowering plants investigated by Heald (12, p. 132) succumbed at $\frac{n}{1600}$ HCl or less.

When copper sulphate was used, Kahlenberg and True (14) found that 0.00062 per cent was sufficient to kill the roots of *Lupinus albus*.

After many experiments, Clark (3, p. 396) concludes that in the case of mineral acids a concentration of 2 to 400 times the strength fatal to the higher plants is required to inhibit the germination of mold spores under favorable conditions.

Bacteria.—Although no direct comparison of bactericidal and fungicidal action is available, the experiments being usually performed under somewhat different cultural conditions, the work of McClintic (17) on zinc chlorid indicates a high resistance of certain bacterial organisms. This investigator found that a 5 per cent solution of zinc chlorid applied for one hour was not sufficient to kill *Bacillus communis*, while a 25 per cent solution required 10 minutes to cause death. At this latter concentration 30 minutes was required to kill another bacterial organism (*Staphylococcus pyogenes aureus*).

Spores of bacteria are well known to be very resistant to various agents. In the case of *Bacillus subtilis*, they are reported to have survived a 50 per cent solution of zinc chlorid for 40 days.

These figures are of interest when one recalls that a 3 to 6 per cent solution of this salt is the usual concentration employed in the preservation of wood.

Yeasts.—Yeasts seem to behave toward many salts and acids very differently from seed plants and fungi. Bokorny (1) has re-

cently reported the effect of about 50 different salts and acids upon yeasts, as compared with other organisms, and has found them generally to be more resistant than algæ or flowering plants. Silver nitrate, which is very deadly to many molds, bacteria, and algæ (the bacterium *Staphylococcus pyogenes* requiring only 0.0002 per cent to check growth; the algæ, *Spirogyra* and *Cladophora*, only 0.0001 per cent), will not kill yeast until the concentration reaches 0.001 per cent. Similarly, mercuric chlorid is toxic to *Spirogyra* in a 0.000001 per cent solution, but a 0.01 per cent solution is required to kill beer yeast.

Molds.—The common molds; such as *Penicillium*, *Aspergillus*, *Sterigmatocystis*, and others, taken as a whole, are highly resistant to toxic agents as compared with the true wood-destroying fungi.

Whereas much experimental work has been done on the former, comparatively little has been carried out on the latter group.

The so-called *Penicillium glaucum* Link., which in the light of recent work has been shown to consist of a group of several distinct species of *Penicillium*, to which the composite name was indiscriminately applied, is one of the most resistant molds recorded. Pulst (23), Clark (3), and Guéguen (10) all agree that from 16 to 21 per cent of copper sulphate is required to stop its growth, and Pulst claims that it will even germinate and fruit in a 33 per cent solution of this salt or a 38 per cent solution of zinc sulphate if allowed to develop a sufficiently long time, i. e., from three to five months.

Clark (3) has tested the effect of some 28 salts and acids upon four or five of the common molds, the tests being made in hanging drop cultures of beet infusion. His table of toxicities indicates that such salts as mercuric chlorid, potassium bichromate, silver nitrate, and potassium chromate are approximately 400 times as effective against these organisms as copper sulphate, sulphuric acid, hydrochloric acid, and zinc sulphate, the comparison being based on molecular solutions.

EFFECT OF COMPOSITION OF MEDIUM ON TOXICITY.

The toxicity of a substance may vary for the same organism when culture media of different compositions are employed. This is due, in large part, to the chemical or physical affinity of some substances for certain constituents of the media, or possibly to some change in the permeability of the plant protoplasm. The well-known reaction of some copper salts with sugars and of mercuric chlorid with albuminous compounds, or the effect of adsorption will serve to illustrate the point.

The most careful work on toxicity has been conducted, using pure distilled water as a medium. However, the use of this method with fungi is practically limited to the germination of spores; nutrient

substances must be added if further growth is desired, and the addition of each nutrient substance introduces a new factor of error.

Unlike bacteria, which can be grown well in synthetic liquid media of known composition, wood-destroying fungi prefer a more complex and solid medium for their satisfactory development. This latter, as a rule, consists of a mixture of meat broth and sugars solidified by agar-agar or gelatin.

Various investigators have used different types of media and different methods, and this accounts in large part for the variability in results. Some, as Clark (3), have used simple plant decoctions, others bouillon, and still others a nutrient agar or gelatin modified in various ways as to available carbon and nitrogen.

Le Renard (16), in his work on *Penicillium crustaceum*, shows that toxicity is closely associated with the composition of the medium and in the same medium varies somewhat with its concentration.

Likewise the presence or absence of certain constituents may determine the temperature which an organism will endure on different media, for Thiele (27) has shown that the maximum temperature for the growth of *Penicillium glaucum* on grape sugar is 31° C.; on salts of formic acid, 35° C.; and on glycerin, 36° C.

Hoffmann (13) states that in the case of *Merulius lachrymans* a slight growth takes place even at 30° C. on certain liquid media, while on solid media (5 per cent agar-agar) the fungus was killed at that temperature. He likewise thinks that as a fungus becomes accustomed to a certain culture medium in its development it gradually overcomes certain unfavorable conditions.

So far as the writers are aware at the present time, the media most satisfactory for the growth of wood-destroying fungi are not free from the objection of being complex, variable, and more or less unknown in their chemical composition; however, certain synthetic media are being developed in the course of the work which show promise of being satisfactory. In an effort, however, to secure results comparable as far as possible with those of certain European investigators, such as Malenković and various workers at Munich, and also Rumbold in this country, the malt-extract agar medium used by these workers has been adopted. This medium will be described later.

EFFECT OF ADSORPTION ON TOXICITY.

The apparent diluting effect which inert, practically insoluble matter exerts on toxic substances has been often observed. For instance, the injurious effect of poisons is not so noticeable when seedling roots are placed in sand and watered with toxic solutions of definite concentration as when grown directly in such solutions. This phenomenon of the removal from solution of a part of the toxic substance by nearly insoluble material, such as glass, quartz, pottery,

hemp and cotton fibers, and starch grains, comes under the general term "adsorption." It is often explained as a direct physical affinity of the toxic chemical for the inert substance; that is, a condensation of the substance on the surface or in the interstices of the insoluble matter, or the formation of a solid solution of the two, but chemists and physicists are not at all in agreement in regard to these explanations.

Among others, True and Gies (29) and True and Oglevee (31) worked upon this problem, using seedlings of *Lupinus albus* and a number of inorganic and organic compounds. As adsorbing agents such substances as sand, glass, filter paper, and paraffin were applied. With copper sulphate they found that at least twice the usual toxic concentration could be endured by the *Lupinus* roots when a sufficient quantity of the insoluble matter was added to the hypertoxic solution. In summarizing their work they remark:

It appears in general that the presence of a considerable body of certain insoluble substances in solutions of strongly toxic compounds both organic and inorganic in their nature, be they electrolytes or not, tends to decrease the toxic activity of the solutions in question. On the whole this ameliorating action is more clearly marked in case the poisonous solutions concerned are dilute solutions of strong poisons than when relatively concentrated solutions of weaker poisons are concerned.

Fitch (8) conducted a series of experiments with sulphuric acid and copper sulphate, using pottery, glass, sand, and filter paper as the adsorbing agents and two common molds (*Aspergillus niger* and *Penicillium glaucum*) as the test organisms. She established for fungi the same phenomena of dilution that a number of other workers had found to hold for flowering plants.

The diversity of results secured when toxic substances are tested on various media, particularly such as contain starch grains and similar materials in suspension, no doubt is explained, in part at least, on the basis of adsorption.

RELATION OF TEMPERATURE TO FUNGUS GROWTH AND TOXICITY.

It is well known that temperature exerts a vital influence on the growth and development of fungi. Not alone is the temperature range which permits the growth of the organisms highly variable, but also the optimum temperature in many cases varies for the different species. Thus, for nine species of wood-destroying fungi studied, Falek (5, 6) indicated a growth range lying between 3° and 44° C., with the corresponding optima between 18° and 35° C. For *Merulius domesticus* (= *M. lachrymans* in part) this optimum falls between 18° and 22° C.¹; for *Coniophora cerebella*, 22° to 26° C.; for *Polyporus vaporarius spumarius*, 26° C.; for *Lenzites abietina*, 29.5° C.; for

¹ Hoffmann (13) states that under certain conditions of culture this optimum may be raised so as to fall between 18° and 26° C.

Lenzites sepiaria, 28° to 32° C.; and for *Lenzites thermophila*, 35° C. Below these temperatures growth becomes greatly lessened as the minimum is approached, while a rise of 4 to 8 degrees above the optimum often causes a total inhibition of growth or even death in the case of very sensitive species.

Different stages of the same fungus may also offer a different resistance to temperature changes, this being much less under moist than under dry conditions. For instance, Falck (7, p. 339) found that fresh fruit bodies of *Merulius domesticus* were killed in 30 minutes at 40° to 42° C., and in 15 minutes at 46° C., while from 12 to 16 hours were required to kill dry spores at 42°.

As compared with this fungus, the same author shows that agar cultures of *Lenzites sepiaria* can survive more than three hours at 60° C.

The resistance of a fungus to toxic substances is greatest under temperature conditions most favorable to its development. After conducting a series of tests on several molds to determine the germinative capacity of the spores in varying concentrations of nitric and sulphuric acids and copper sulphate at different temperatures, either directly in the solutions or after removal to nutrient media following immersion for 24 hours, Brooks (2) states that "in most cases the deleterious action increased very rapidly with rise in temperature," but that "in all instances the injurious effects were least at the optimum for the fungus."

RELATION OF LIGHT TO FUNGUS GROWTH.

Light also exerts an appreciable effect on the development of wood-destroying fungi. This is evidenced in two ways: (1) By its influence on the growth of the mycelium, and (2) by the rôle it plays in the production of normal fruiting bodies. In most instances at least, partial illumination is essential to normal fruiting. The effect on the rate of growth of the mycelium, however, is less marked, but still quite appreciable. Of seven species of wood-destroying fungi studied, Hoffmann (13) reports that growth in the dark was from 4.1 to 17.8 per cent (average 9.9 per cent) better than in sunlight. In carrying his experiments still further and examining the effect of the red and blue ends of the spectrum, respectively, he found that the former gave 2.6 per cent better growth in the case of *Paxillus acheruntius* and 59.3 per cent in the case of *Polyporus vaporarius* (average for nine fungi 14.6 per cent).

WHAT DETERMINES TOXICITY?

An adequate discussion of the subject of what determines toxicity would lead us into one of the most difficult fields of biological chemistry and physiology, hence, for the purposes of this publication, the writers omit reference to a great mass of literature covering the

more involved aspects of the question and merely bring forward a few of the points which serve to illustrate certain phases.

In the previous discussion it has been seen that the degree of toxicity manifested is relative and closely associated with the environmental conditions and the particular physiological constitution of the individual organisms under consideration, as well as with the concentration of the different toxic substances employed and the chemical and physical relations which these bear to the media upon which the organisms are grown. Why certain concentrations of substances are toxic to one plant and not to another, or why the same species varies in its tolerance to a certain toxic agent, is more or less obscure. According to Heald (12, p. 126) it may be a case of "adaptation and adjustment," and this is at least suggested by the work of Pulst (23) in increasing the resistance of *Penicillium glaucum* to copper sulphate. In support of his view Heald further states:

Those substances which are poisonous to plants are generally such substances as are not accessible to plants in their normal habitats, at least to any extent, while those substances which are generally present in the soil have no injurious effect, or at least not in the same degree of concentration at which we find them in the soil.

However, for the purposes of the present paper the question of how the toxic substances exert their effect is not so near to the point as is the question of what particular components of the substances are the effective ones. On the basis of the separation of compounds into their constituent ions (elements or radicals) when brought into solution, many efforts have been made by comparison of different substances which have certain ions present in varying proportions to determine the most active part of the molecule. As many substances, particularly the more complex, do not become completely dissociated in solution, experimental work largely draws its inferences from the simpler compounds, mainly the inorganic.

As a result of work on such ionized molecular solutions, investigators quite generally agree that in case of the salts of heavy metals, like copper and mercury, it is the metallic ion that is largely effective. In the case of strong acids, such as hydrochloric and sulphuric, the hydrogen ion is said to be the principal toxic element. The work of Kahlenberg and True (14) proves the great activity of hydrogen and shows that in mixtures of such acids the toxicity is proportional to the number of free hydrogen ions present.

In 1900 True (28) published an account of the investigation of 20 acids, both inorganic and organic, together with their sodium salts, in an effort to extend our knowledge of the effective toxic elements, the toxicity tests being conducted on the roots of *Lupinus albus*. With the simple inorganic acids, which readily dissociate in solution, he corroborated earlier views that the H ion gives the greater part of the toxicity to the solution, the corresponding sodium salts of the

acids being only slightly toxic. With the organic acids, in which ionic dissociation is usually less complete, he also found that the relative importance of the H ions in general varied with the percentage of dissociation. If the dissociation was relatively slight, the nonionized molecule itself exerted the predominating influence. In general, the anions of organic acids were found to possess relatively slight toxic properties, oftentimes so slight as to be almost negligible, and, since both the sodium ions and the anions were usually but weakly toxic, it followed, as a rule, that sodium salts showed but 0.5 to 3 per cent of the toxic value of the corresponding acids. Carboxyl hydrogen proved much more toxic than hydroxyl hydrogen. Since in the phenols this latter form of combination occurs, and since these substances do not ionize, the toxicity here must be referred entirely to the undissociated molecule.

In order to throw further light on the behavior of phenols and their derivatives True and Hunkel (30) extended their investigations on *Lupinus albus* to this group. The results bear out their earlier conclusions that electrolytic dissociation of phenylic bodies plays but a very subordinate rôle in determining their toxicity. However, in a few instances, such as with picric and salicylic acids, the cresols, and the mononitrophenols, electrolytic dissociation is said to exert a pronounced influence. Some phenols also, like pyrocatechol and hydroquinone, which are comparatively unstable, may quickly change to constituents even more fatal than H ions. Certain radicals seemed also to have specific properties when introduced into the molecule. For instance, the number of hydroxyl groups appeared to have little influence, while the introduction of the methyl group into the benzene nucleus increased the toxicity to a considerable but variable degree, as shown by the cresols and less plainly by orcinol; however, replacing the H of a hydroxyl group by a CH_3 group had little effect. The introduction of the isopropyl group into the cresols further increased their toxicity. The presence of one or more nitro groups likewise increased toxicity to a great degree, but the number of these groups seemed to make little difference.

Similarly, in the case of certain organic compounds (cf. 7, pp. 351-352), Ehrlich and Bechhold have shown that the introduction of halogen and alkyl groups into the benzol ring increases the toxicity of phenols to diphtheria bacteria, two molecules of pentabromophenol being about equal to 40 molecules of trichlorophenol and 100 molecules of phenol. On the other hand, the introduction of the carboxyl group was said to lessen toxicity.

Likewise, Falck (7, pp. 355, 357) states that nitrophenols and dinitrophenols are considerably more toxic than phenol and more so when the nitro groups are in the ortho position than when in the meta or para position. The most effective of 19 nitrophenols which he tested

in Petri dishes on agar against the fungus *Coniophora cerebella* were the sodium or potassium salts of dinitrophenol ($C_6H_3 \cdot (NO_2)_2[2.4]ONa$) and dinitro-orthocresol ($C_6H_2 \cdot CH_3[2] \cdot (NO_2)_2ONa$).

Generalizations, however, are not always applicable by analogy and may serve only for certain limited groups. In his work on numerous fluorin salts Netzsche (21) found that the fluorin ion was the most active, the relative toxicity of the simpler and consequently more readily dissociated salts, at least, being in direct proportion to the amount of fluorin in the molecule. When the acid (HF) itself, however, was under consideration it was found to be even more toxic than its simple metallic salts, indicating the great activity of free hydrogen.

TESTS OF THE TOXICITY OF WOOD PRESERVATIVES.

It is only within the past decade that laboratory tests to determine the relative toxicity of substances adapted particularly to wood preservation have been undertaken. These lack the refinement of earlier work, as it was not the intention to enter into the question as to why and how a substance was toxic, but merely to determine how much of a given poisonous substance was necessary to inhibit the growth of fungi, particularly the wood-rotting forms. The result is that different investigators have used different methods, different culture media, different organisms, temperature conditions which were often not the optimum for the fungi concerned, and oftentimes also impure chemicals and composite oils, such as creosotes, that no other investigator is able to duplicate except from the same sample.

The problem has been attacked in two ways: (1) By mixing the preservative under consideration with various types of culture solutions, usually solidified by the addition of agar-agar or gelatin, and inoculating with the organisms desired; and (2) by injecting the preservative into wood and exposing the blocks thus treated to the action of wood-destroying fungi.

Tests of this sort were first suggested by Malenković (18) in 1904. The results of his work were first published in an Austrian military journal and later (19) amplified and printed in book form. He lays no claim to refinement of work, so it is difficult to correlate his results with later ones, except in a general way. The larger part of his experiments were carried out by injecting the preservative into wood, but a few beaker tests were made according to the following plan:

Five glass beakers were filled with 100 c. c. of 10 per cent gelatin or 2 per cent agar media, and to each was added a certain amount of the antiseptic, such as 0.5, 1, 1.5, and 2 grams. The media were then melted, thoroughly stirred, and allowed to cool. Then, without any previous sterilization, a trace of some mold (unknown to the experimenter) was transferred to the surface of the media, and the cultures were set away in a dark, damp place. After 14 days observations were made to determine whether the surface had become moldy. The concentration that prevented mold growth was recorded as the toxic point for the preservative in question.

As has been shown in the preceding discussion, tests that are conducted under any other than pure-culture conditions are not directly comparable with each other, for the different organisms react in an entirely different way to the same chemical substance. Moreover, the use of molds which at most produce but slight effect upon wood gives no more than the roughest approximation as to how wood-destroying organisms would behave under similar conditions.

In 1910 Netzschn (21) conducted an exhaustive series of experiments on the toxicity of fluorin compounds. As these compounds have only recently entered into the field of wood preservation, and as many of them have proved to be toxic agents of high efficiency, his work is of great technical value. He carried out the work much as Malenković and other investigators have done, both by mixing the substances in gelatin culture media and injecting them into wood, but his tests on culture media were carried out under sterile conditions in flasks, test tubes, or Petri dishes, so that many of the objections to the work of Malenković were eliminated. Into the gelatin media were introduced varying proportions of equimolecular solutions of the fluorin compounds. The culture vessels were then inoculated, using both *Coniophora cerebella* (a true wood destroyer) and the green mold, *Penicillium glaucum*, the former being maintained for about four weeks in an incubator at 20° to 21° C. His results, showing the point of inhibition of growth, are presented on the basis of one gram molecule of the preservative to the number of liters of culture media necessary to secure the proper concentration. In the present paper this ratio has been changed to the percentage basis (weight of preservative in volume of media), in order to compare his results with those of other investigators.

About this same time Seidenschnur (26), head chemist of the wood-preservation laboratory of the Rütgerswerke-Aktiengesellschaft, at Berlin (Charlottenburg), presented the results of a few tests upon the comparative toxicity of zinc chlorid and tar oils. His experiments were conducted in test tubes containing gelatin media mixed with varying proportions of the antiseptics. After the mixture was prepared, the tubes were sterilized for one-half hour at 80° C.¹ The tubes were then slanted and inoculated with *Penicillium glaucum*. The toxic point was not determined, but the relative efficiency of the two substances was compared in parallel cultures.

During 1911, J. M. Weiss (33, 34), chemist in the technical laboratories of the Barrett Manufacturing Co., New York City, published the results of a number of experiments to test the relative antiseptic value of creosotes and other oils. The substances were mixed in agar media. The organisms used consisted of a bacterium (*Bacillus subtilis*), a yeast (*Saccharomyces glutinis*), and a species of *Penicillium*.

¹ This treatment, however, is usually considered insufficient to insure sterility.

An effort was made to handle them in pure culture under sterile conditions. The selection, however, of test organisms which play at most but a slight rôle in the decay of timber is not to be recommended. As many factors of error as possible should be eliminated from such tests, for there are certain to be many remaining after all precautions are taken.

During the same year Rumbold (25) carried out a series of tests with different wood preservatives, using agar media in Petri dishes as well as toasted bread soaked in the antiseptics. In the case of the agar cultures, the media and preservative were mixed before sterilization. This procedure is known to lead to very erroneous results with certain substances, such as zinc chlorid and copper sulphate. In all cases the preservative and media should be sterilized separately and heated no higher than is necessary during the mixing, in order to avoid as far as possible any chemical combination which tends to occur. The higher concentrations of the salts mentioned above cause a liquefaction of agar or gelatin media when sterilized together. One test conducted in our laboratory showed that zinc chlorid at 0.6 per cent concentration when sterilized after mixing allowed even more growth of *Fomes annosus* than 0.2 per cent when the two components were not sterilized together. Concentrations of the sterilized mixture below about 0.4 per cent appeared to be stimulative, giving a white, fluffy growth, which was more luxuriant than in the creamy check cultures and which grew up over the under side of the covers of the Petri dishes.

The use of bread for culture media likewise is objectionable, for the starch therein contained possibly acts as a diluting agent, as already indicated in the discussion of the phenomena of adsorption. For instance, in comparing Rumbold's tests of sodium carbonate on bread and on agar it is seen that considerably more of the preservative is required to check the growth of the organisms when the former medium is used.

In 1912, Falck (7), and Dean and Downs (4), published the results of work on various wood preservatives in agar media, using wood-rotting organisms.

The former covered a wide range of possible preservatives (some 60 or 70), including phenols and cresols and their derivatives, benzol derivatives, fluorin compounds, acids, alkalies, and inorganic metallic salts. The work appears to have been very carefully done and is an extremely valuable contribution to the subject. It is open to the objection, however, that the tests were of too short a duration.

Dean and Downs report only a few tests on tar oils in a bean-agar medium, using the cosmopolitan wood-rotting fungus *Polystictus versicolor*. These investigators introduced a method of preparing creosote emulsions with gum arabic, which was considered advanta-

geous,¹ particularly with heavy oils. They also attempted to improve upon the usual method of inoculating the surface of the culture with the mycelium of the test organism by cutting a small block out of the medium, placing the transferred mycelium in the aperture, and then covering this with the portion of medium which was originally removed. They claimed this would give a more accurate indication of whether the fungus was really growing on the treated medium or only on the fragment of medium which must necessarily accompany the mycelium when it was transferred. This appears, however, from work in our laboratory, to be a refinement of doubtful expediency, for it has often resulted that when fresh, actively growing mycelium is placed in intimate contact with the poison it will be directly killed, while if it has the opportunity to recover its vigor to a certain extent after the disturbance in its growth equilibrium, due to cutting and removal from the original culture, it may eventually withstand concentrations which would otherwise be fatal.

The more important results of these different investigators are presented in Table IV (pp: 31-34).

TESTS CONDUCTED AT THE FOREST-PRODUCTS LABORATORY.

SCOPE OF THE WORK.

The experimental work in wood preservation at the Forest-Products Laboratory includes a physical, chemical, and pathological examination of various substances which may have a possible value in the industry (32). Therefore, since toxicity is but one factor, conclusions regarding the service value of these substances should not be drawn without giving due consideration to other factors.² The pathological tests are made in Petri dishes, using agar media, or by injecting the preservatives into wood and exposing the wood to the action of wood-destroying organisms. Only the Petri-dish method is herein described. This method has the advantage of giving results from which at least tentative conclusions can be drawn in a relatively short time. Conversely, it is open to certain objections for which due allowance must be made in generalizations regarding the possible behavior of a preservative when placed under service conditions. However, in experimental work on the toxicity of different chemical substances it is often very necessary to secure indicative results as soon as possible. In this way many substances may be eliminated which are not worthy of further trial. After a preservative has been shown to possess high toxic properties under

¹ From the purely physical side of preparing the preservatives so they can be more readily handled the gum-arabic emulsions have proved satisfactory to the writers, but the gum arabic apparently reduces the toxicity to such an extent as to forbid its use in comparative tests. This fact has been determined since this manuscript was prepared.

² See U. S. Dept. of Agriculture Bulletin 145, "Tests of wood preservatives."

Petri-dish conditions, tests on its properties when injected into wood should follow, under both laboratory and service conditions.

Recently, an attempt has been made by a European investigator (20) to correlate Petri-dish results directly with service values. First, the preservatives were grouped as nearly as possible according to their permanence in wood. Then, knowing the average length of life of the treated timbers, the amount of preservative necessary to inject to give this life, and the toxic point of the substances as indicated by Petri-dish tests, a curve was plotted using the first factor as the axis of ordinates and the ratio existing between the second two as the axis of abscissas. From this curve the investigator would predict the possible service value of any new preservative of like permanence in wood merely from the known Petri-dish ratio by locating the point at which its ordinate intersects the standard curve.

Such mathematical calculations are interesting, but must necessarily be very limited in their application, since such variables as the solubility and volatility of the preservatives, the nature of the timber treated, and the soil and weather conditions to which the treated wood is exposed must necessarily exert a great influence on the length of the life of the material.

At the Forest-Products Laboratory, 2,400 Petri-dish tests have been made to date on 54 different substances; however, not all are sufficiently complete to be reported. These include a few water-soluble salts, but in the main they comprise various oils and tars. These preservatives have been for the most part submitted by American and European cooperators interested in having the substances examined.

The tests were conducted using two wood-destroying organisms, *Fomes annosus* Fr. and *Fomes pinicola* (Sw.) Fr., which have a wide American and European distribution and are very important in the decay of wood, particularly coniferous timber. The former is undoubtedly the most serious fungus of coniferous mine timbers in the United States.

In general, the molds used by other investigators may be considered more resistant than the true wood-destroying fungi, but the writers have considered it advisable to use only wood-destroying forms, in order to eliminate any possibly erroneous inferences.

METHODS OF TESTING TOXICITY.

The method of conducting the tests was in principle the same as that used by other investigators, merely involving the mixing of the various preservatives in definite proportions with media nutrient to fungi. However, an attempt was made to refine the methods as far as possible, so as to eliminate certain sources of error to which attention has already been called.

A culture medium made according to the following formula was used:

Extract of 1 pound lean beef in distilled water.....	1,000 c.c.
Löfflund's malt extract.....	25 grams.
Agar-agar.....	20 grams.
(Carefully filtered, but reaction not adjusted; slightly acid.)	

This is the formula largely used by German investigators. It is a good medium for the development of fungi, but, like all other media of organic and often unknown composition, offers the objection of possible chemical reaction with certain preservatives. However, such synthetic media as were experimented with proved very poor substrata for the development of the organisms.

The above medium after melting was measured¹ into 50-c. c. glass bottles with carefully ground glass stoppers, usually 17 c. c. to a bottle, using a standardized 17-c. c. pipette or a 25-c. c. graduate. One check was usually prepared for each series of concentrations and to this was added sufficient distilled water to make 20 c. c. The stoppers were then sealed in with a rubber-glycerin burette-cock grease and capped with a small piece of muslin. The bottles were clamped in specially constructed frames (Pl. I, fig. 1) and given a sterilization of 25, 20, and 20 minutes, respectively, at 100° C. on successive days.

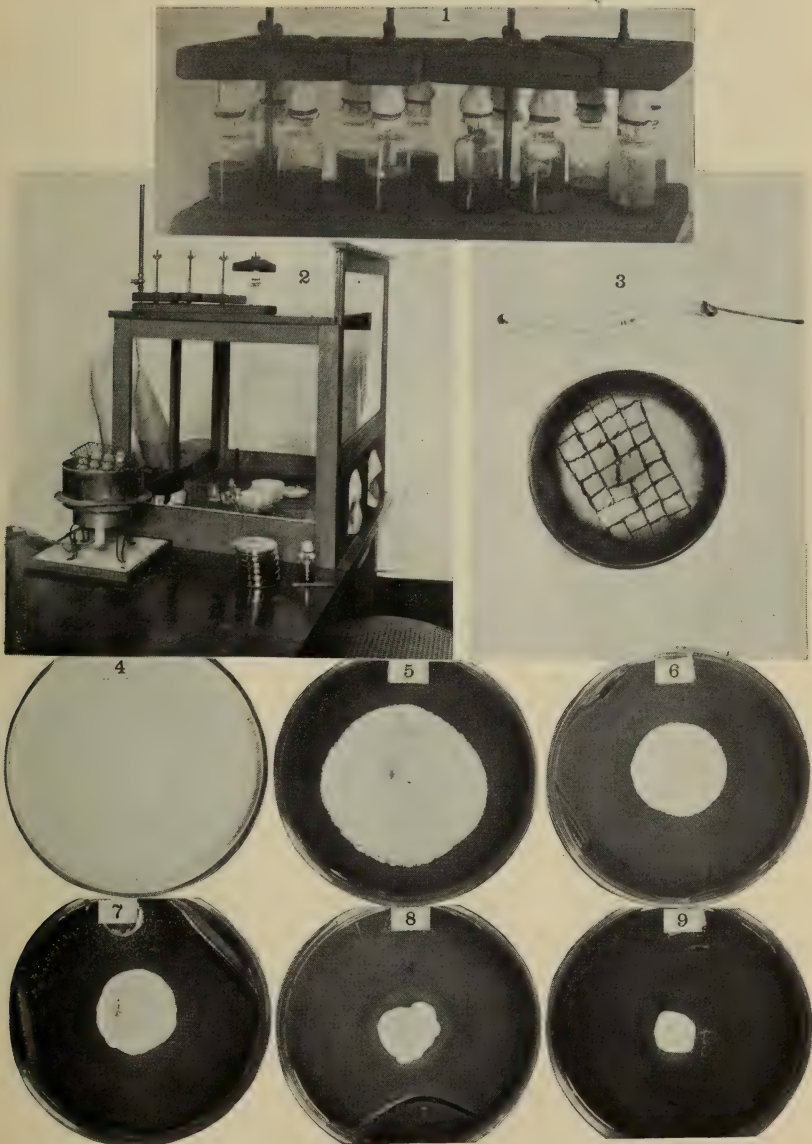
The handling of the preservatives involved slight modifications for individual cases, but in all instances concentrations are based on the actual weight of the preservatives in grams in 20 c. c. agar-preservative mixture.

With inorganic salts soluble in water solutions were prepared varying from 3 to 10 per cent concentration (grams in 100-c. c. solution), and these were used by measuring into 50-c. c. bottles, similar to those used for agar, the desired amount of solution, using either a 10-c. c. or a 25-c. c. standardized burette graduated in twentieths or tenths of a cubic centimeter, respectively. To each bottle was then added sufficient distilled water to make 3 c. c. In all cases concentrations were based on the weight of dry salt present.

All other preservatives were weighed into the 50-c. c. bottles on an analytical balance, and enough distilled water was added to make 3 c. c. In the case of a few viscous oils, namely, coal-tar creosote, coal-tar creosote Fraction V, wood tar, and wood creosote, which do not readily emulsify with water, 5 to 33½ per cent stock emulsions² were prepared, using equal amounts of gum arabic and preservative and diluting with distilled water to the desired concentration. These emulsions were then used in place of the crude preservatives.

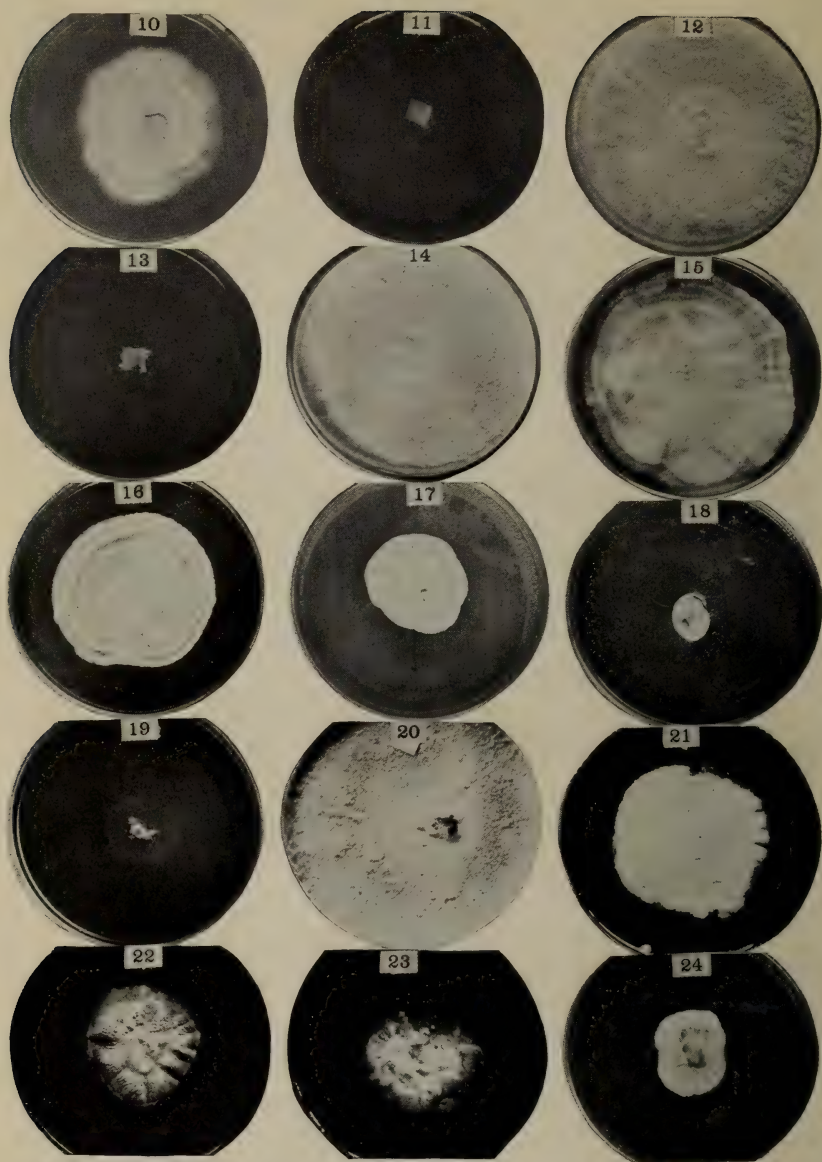
¹ In all measurements of agar one-half c. c. excess was allowed to cover the amount adhering to the glass containers.

² This method usually produced a quite permanent emulsion.



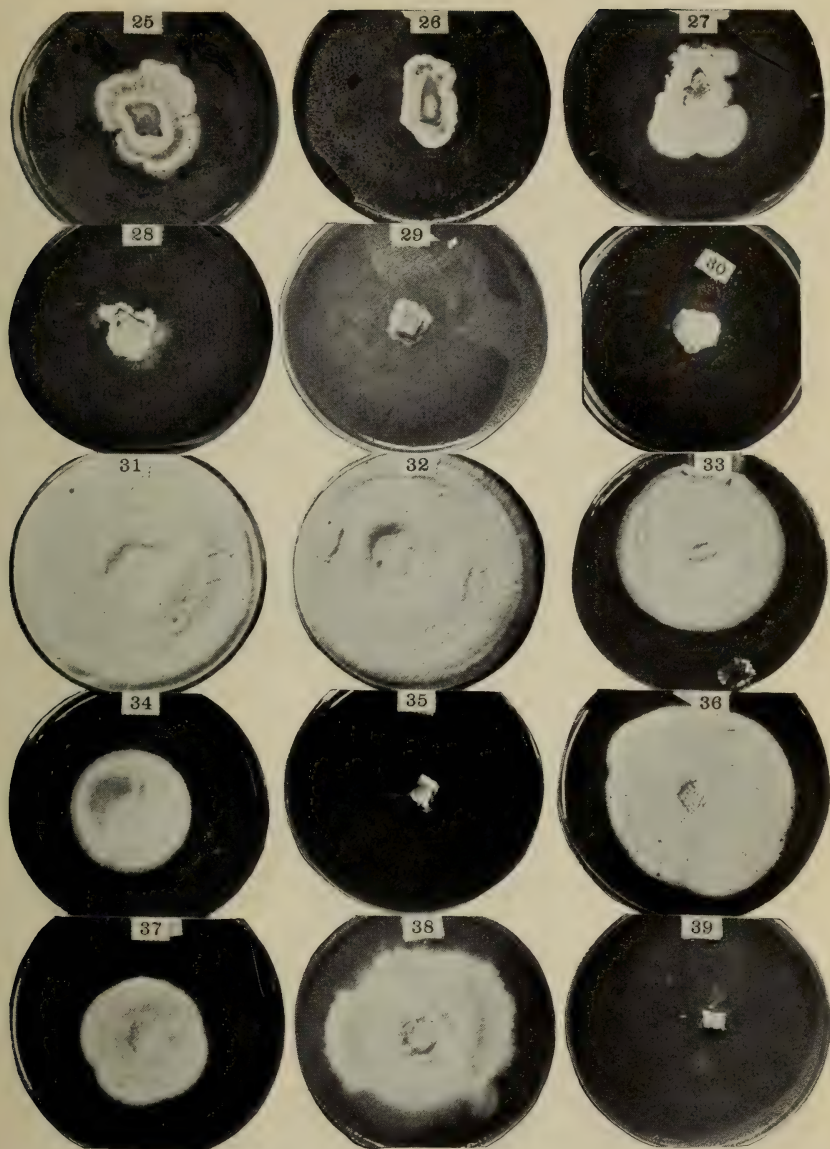
TOXICITY STUDIES: APPARATUS AND PETRI-DISH CULTURES.

FIG. 1.—Frame for agar and preservative bottles during sterilization. FIG. 2.—Inoculation case, showing water bath on hot plate and other apparatus used. FIG. 3.—Petri-dish culture of *Fomes annosus* cut into squares ready for transferring to the test plates; platinum needle with flattened tip used in the operation. FIGS. 4 to 9.—Petri-dish cultures of *Fomes pinicola* on different concentrations of coal-tar creosote, grade C, after 5 weeks: 4, Check; 5, on 0.075 per cent; 6, on 0.1 per cent; 7, on 0.125 per cent; 8, on 0.15 per cent; 9, on 0.175 per cent.



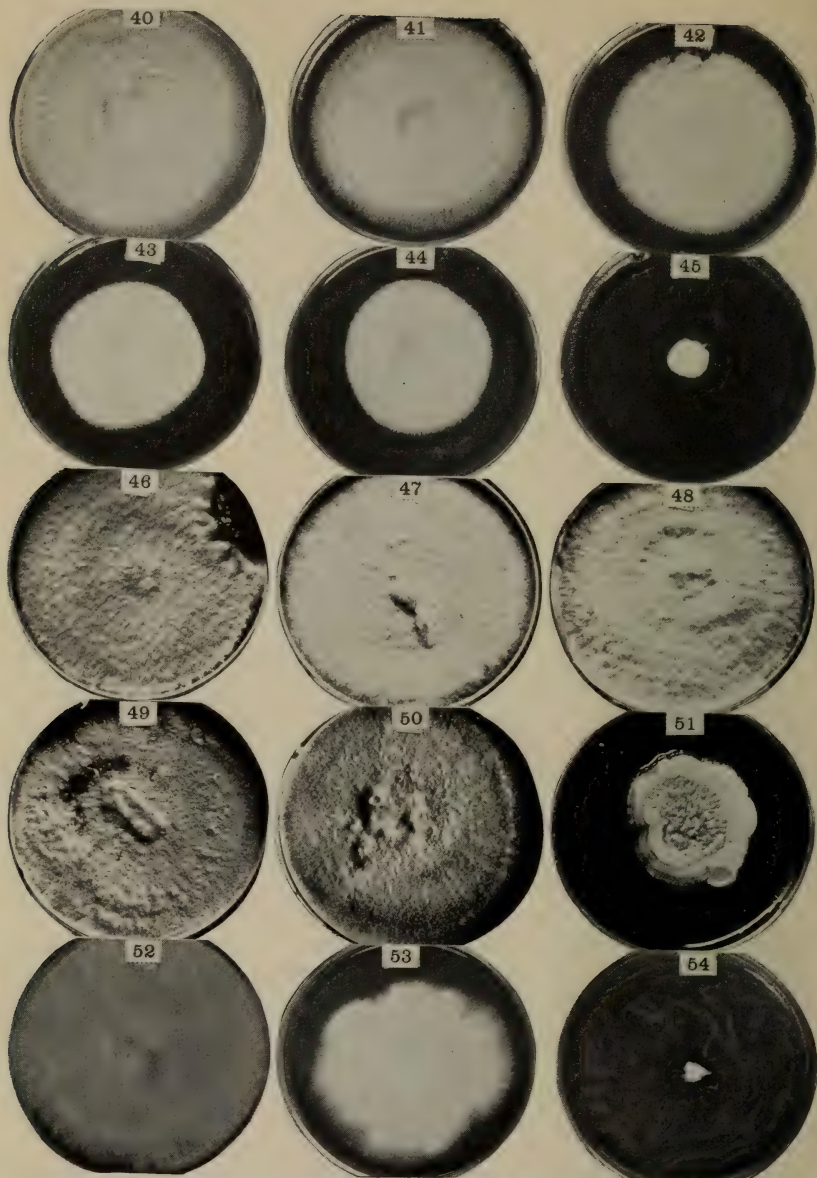
TOXICITY STUDIES: PETRI-DISH CULTURES OF FOMES ANNOSUS AND FOMES PINICOLA.—I.

FIGS. 10 and 11.—*F. annosus* on different concentrations of coal-tar creosote, Fraction I, after 5 weeks: 10, on 0.275 per cent; 11, on 0.3 per cent. FIGS. 12 and 13.—*F. pinicola* on different concentrations of coal-tar creosote, Fraction II, after 5½ weeks: 12, on 0.125 per cent; 13, on 0.15 per cent. FIGS. 14 to 19.—*F. pinicola* on different concentrations of coal tar creosote, Fraction IV, after 9 weeks: 14, Check; 15, on 0.025 per cent; 16, on 0.05 per cent; 17, on 0.075 per cent; 18, on 0.1 per cent; 19, on 0.125 per cent. FIGS. 20 to 23.—*F. annosus* on different concentrations of coal-tar creosote, Fraction V, after 7 weeks: 20, Check; 21, on 0.1 per cent; 22, on 0.5 per cent; 23, on 1 per cent. FIG. 24.—*F. pinicola* on 1 per cent concentration of coal-tar creosote, Fraction V, after 6 weeks.



TOXICITY STUDIES: PETRI-DISH CULTURES OF FOMES ANNOSUS AND FOMES PINICOLA.—II.

Figs. 25 and 26.—*F. pinicola* on different concentrations of United Gas Improvement Co. 1.07 oil, No. 1101, after about 5 weeks: 25, On 20 per cent; 26, on 40 per cent. Figs. 27 and 28.—*F. annosus* on different concentrations of water-gas tar distillate (sp. gr. 0.995 at 60° C.), after 6 weeks: 27, On 0.2 per cent; 28, on 0.3 per cent. FIG. 29.—*F. annosus* on 2.2 per cent concentration of S. P. F. carbolineum after about 6 weeks. FIG. 30.—*F. annosus* on 0.15 per cent concentration of coal-tar creosote, Fraction III, after 6 weeks. Figs. 31 to 35.—*F. pinicola* on different concentrations of wood creosote (Douglas fir) after about 2½ weeks: 31, Check; 32, on 0.05 per cent; 33, on 0.1 per cent; 34, on 0.125 per cent; 35, on 0.15 per cent. Figs. 36 and 37.—*F. annosus* on different concentrations of wood creosote (Douglas fir) after about 4 weeks: 36, On 0.2 per cent; 37, on 0.4 per cent. Figs. 38 and 39.—*F. annosus* on different concentrations of cresol calcium after about 6 weeks: 38, On 0.14 per cent; 39, on 0.28 per cent.



TOXICITY STUDIES: PETRI-DISH CULTURES OF FOMES ANNOSUS AND FOMES PINICOLA.—III.

FIGS. 40 to 45.—*F. pinicola* on different concentrations of wood tar (hardwood) after 2 weeks: 40, Check; 41, on 0.2 per cent; 42, on 0.3 per cent; 43, on 0.4 per cent; 44, on 0.5 per cent; 45, on 0.6 per cent. FIGS. 46 to 48.—*F. annosus* on different concentrations of wood tar (hardwood) after about 3 weeks: 46, On 0.1 per cent; 47, on 0.5 per cent; 48, check. FIGS. 49 to 51.—*F. annosus* on different concentrations of copperized oil: 49, On 0.5 per cent after about 3 weeks; 50, on 1.75 per cent after about 3 weeks; 51, on 36 per cent after about 5½ weeks. FIG. 52.—*F. pinicola* on 50 per cent concentration of None-Such Special after about 3½ weeks. FIGS. 53 and 54.—*F. pinicola* on different concentrations of zinc chlorid (commercial) after 4 weeks: 53, On 0.7 per cent; 54, on 0.75 per cent.

In a few instances where the preservatives were low in toxic properties more than the specified 3 c. c. was necessary in order to secure the higher concentrations, and in these cases it became necessary to take into consideration the excess of preservative, and, considering it roughly as having the specific gravity of water, to reduce the agar by just this amount, in order that the combined volume might not exceed 20 c. c.

The concentrations to be used in the first series¹ of experiments on a given preservative were governed largely by the judgment of the investigator. The results thus obtained usually determined between what limits it was necessary to continue the work. The experiments were then carried on between these points, usually to within an accuracy of about 10 per cent for the actual and total inhibition point for each preservative. Thus, if growth stopped at 0.5 per cent or below, the tests were carried to the nearest 0.05 per cent; if between 0.5 and 1 per cent they were carried to the nearest 0.1 per cent, and so on up to the highest concentrations employed, usually 40 per cent, which would thus be tested to the nearest 4 per cent. This 40 per cent concentration is equivalent to an injection of 24.9 pounds of the preservative per cubic foot, and it was thought unnecessary from a practical standpoint to go above this point.

After the proper quantities of preservative had been placed in 50-c. c. glass-stoppered bottles, these were sealed and sterilized in exactly the same way as the agar bottles and along with them.

As a few experimental weighings before and after sterilization indicated that no loss occurred, even of such volatile substances as are contained in the lowest fractions of coal-tar creosote, the method may be considered safe.

After sterilization, both the agar and preservative bottles were heated on the water bath, then transferred to a sterile culture case (Pl. I, fig. 2), where the hot agar was poured into the preservative bottle and thoroughly mixed. In some cases one or two sterile glass beads were added to the preservative bottles to facilitate the mixing. These were removed later.

The agar-preservative mixtures were then poured into sterile Petri dishes 100 mm. in diameter and 10 mm. deep. After cooling, each plate was inoculated at the center with a weft of mycelium 5 or 6 mm. square, cut from a Petri-dish culture (Pl. I, fig. 3) 2 to 3 weeks old of the fungus desired, either *Fomes annosus* Fr. or *Fomes pinicola* (Sw.) Fr. The dishes thus prepared were then placed in an incubator and held at approximately 25° C. for periods varying from 4 to 10 weeks, usually from 4 to 6.

¹ A series consists of a set of progressively increasing concentrations of a given preservative, tested at the same time against the action of a single fungus.

In addition to the possibility, in some instances, of chemical combinations between the preservative and the media, there will also necessarily be a slight change in concentration, due to the drying out of the media when held in Petri dishes for six to eight weeks. Likewise, during this interval of time certain volatile constituents, particularly the lighter oils, may escape from the media.

In recording observations of the behavior of the fungi toward the preservative, rapidity and amplitude of growth, together with any other peculiarities in appearance, were noted, inspection being made about once a week.

One very interesting feature of the tests was the development of a "halo" around either the living or the dead transfers, or in advance of the fungous growth on the check cultures. These halos differed in appearance on the different preservatives, sometimes being lighter, sometimes darker, than the surrounding medium. In order to determine whether the change was due to advance submerged hyphae, several transfers were made from the halos to fresh sterile agar, but as no living organisms were demonstrated by this test or by microscopical examination to be present it appears to be an advance physicochemical change in the media, arising, perhaps, from the diffusion of enzymes from the transfer, as Kellerman (15) has recently demonstrated for cytase produced in fungus cultures.

DEVELOPMENT OF *FOMES ANNOSUS* AND *FOMES PINICOLA*.

IN NONTOXIC CHECK CULTURES.

In the check cultures, *Fomes annosus* produces a rather compact creamy growth (Pl. II, fig. 20, and Pl. IV, fig. 48), forming an abundance of the characteristic conidia described by Brefeld. *F. pinicola* (Pl. I, fig. 4; Pl. III, fig. 31; and Pl. IV, fig. 40), on the other hand, develops a fluffy, deep, white mycelium of considerably more rapid growth than *F. annosus*. At 25° C., *F. pinicola* develops a radial growth of 24 mm. in 9 days (average of 14 tests) and covers the plate in 15 days (15 tests); *F. annosus* develops 15 mm. in 8½ days (19 tests) and covers the plate in 20½ days (12 tests).

IN CULTURES CONTAINING TOXIC SUBSTANCES.

The rate of growth of each of these two fungi on toxic media is usually considerably retarded, in many cases strongly so, as compared with check cultures. In some instances where very low concentrations of certain substances are used, a stimulating effect is observed, but this condition is reversed with increased concentrations. The stimulated growth on zinc-chlorid concentrations when heated in the presence of the culture media (such concentrations often being far above those necessary to kill when not so heated together) is

readily explained on the basis of chemical combination with the media.

The length of time required to make an initial growth on different toxic media varies from a very few days up to seven weeks or more; check cultures usually start within two or three days. Table I illustrates this for a few preservatives.

TABLE I.—Time required by *Fomes annosus* on 0.2 per cent concentrations and *F. pinicola* on 0.1 per cent concentrations to make initial growth from mycelium at 25° C.

Preservative used.	<i>F. annosus.</i>	<i>F. pinicola.</i>
	<i>Days.</i>	<i>Days.</i>
Check cultures.....	2 to 3	2 to 2
Sodium fluorid.....	20	24
Coal-tar creosote.....	18	21
Coal-tar creosote, Fraction II.....	15	18
Coal-tar creosote, Fraction III.....	40	23
Coal-tar creosote, Fraction IV.....		53

It is thus seen that no growth demonstrable to the naked eye on any of the concentrations mentioned occurred within a period of two weeks, and the error which would occur in discontinuing the tests at the end of 8 to 10 days, as several investigators have done, becomes very evident.

RECORD OF TESTS CONDUCTED.

A description of each of the 18 preservatives used, accompanied by individual tables and notes showing the rate, amplitude, and appearance of growth on the different concentrations, as compared with the check cultures, is given on the following pages. Under the heading "Concentration of the preservative" in each table the average radial distance to which the fungus has grown from the margin of the transfer at the end of the test is indicated by numerals,¹ the position of the first zero marking the killing point: Thus, 4=30 to 40 mm.; 3=20 to 30 mm.; 2=10 to 20 mm.; 1=1 to 10mm.; 0=no growth.

Sodium fluorid.

[Laboratory sample No. 1929. Purchased from Eimer & Amend, Chicago, Ill.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).					
	Number.	Duration.		0.05	0.1	0.15	0.2	0.25	Check.
		<i>Weeks.</i>							
<i>Fomes annosus</i>	9	4	1	4	3	2	1	0	4
<i>F. pinicola</i>	11	5 to 7	1	3	2	0	.....	.....	4

¹ It should be kept in mind that the growth rate designated as "4" is not necessarily the same on different preservatives or different concentrations of the same preservative. All cultures which have produced a growth of at least 30 to 40 mm. radius at the end of the test are included. Some of these may have reached this point in two to three weeks, as in the case of the checks, while others may have required the full test period; hence, the data as presented show only the relative retarding effect of the higher concentrations.

Fomes annosus: In one week, the radial growth of the check was 15 mm.; 0.05 per cent, 20 mm.; 0.1 per cent, 15 mm.; 0.15 per cent, 3 mm. In four weeks concentrations up to 0.15 per cent showed 20 to 30 mm.; 0.2 per cent, about 2 mm. Thus, the rate of growth on 0.05 and 0.1 per cent concentrations equaled or exceeded that of the checks, but the higher concentrations produced a decided inhibition. The growth on the toxic media appeared very much as on the check.

Fomes pinicola: In two weeks, the radial growth of the check was 40 mm.; 0.05 per cent, 9 mm.; 0.1 per cent, 4 mm.; no growth on 0.15 per cent. After four to six weeks, no growth on 0.15 per cent. The growth on the toxic media was fluffy, white, and quite similar in appearance to that on the check.

Zinc chlorid.

(Pl. IV, figs. 53 and 54.)

[Laboratory sample No. 2239. Cooperator, Grasselli Chemical Co., Cleveland, Ohio. Commercial salt, meeting the specifications of the American Railway Engineering and Maintenance-of-Way Association.]

Fungus.	Tests.		Times killing point ver- ified.	Concentration of the preservative (per cent).											
	Num- ber.	Dura- tion.		0.1	0.2	0.3	0.4	0.45	0.475	0.5	0.6	0.65	0.7	0.75	Check.
Fomes annosus.	33	Weeks. 5 to 8	1	4	1	1	1	1	1	0					4
F. pinicola.....	33	4 to 8	2								4	4	4	0	4

Fomes annosus: In 18 days, the radial growth of the checks reached about 35 mm.; 0.05 per cent, about equal to check; 0.15 per cent, 8 mm.; 0.3 per cent, 1 mm. There was usually no growth on higher concentrations until after about four weeks, and it was comparatively slight even after six to eight weeks, reaching only 1 to 8 mm. The toxic cultures generally were denser and of brighter tan color than the check.

Fomes pinicola: In two weeks, the radial growth of the check reached 40 mm.; 0.6 and 0.7 per cent, 10 mm. After four weeks, 0.6 and 0.7 per cent reached 35 mm. On the lower concentrations the growth was more fluffy than that on the check.

Sapwood antiseptic.

[Laboratory sample No. 1611. Cooperator, J. M. Long, Chicago, Ill. Formula (by weight, in water solution): NaCl, 2.92 per cent; CaSO₄, 0.246 per cent; ZnSO₄+7 H₂O, 0.246 per cent; CuSO₄+5 H₂O, 0.182 per cent; FeSO₄+4 H₂O, 0.0605 per cent.]

Fungus.	Tests.		Times killing point ver- ified.	Concentration of the preservative (per cent)						
	Num- ber.	Dura- tion.		16½	25	30	50	60	75	Check.
Fomes annosus.....	17	Weeks. 4 to 5	.....	4	4	3	2	2	1	4

Fomes annosus: In about three weeks the radial growth of check reached 40 mm.; 50 per cent, 10 to 15 mm.; 75 per cent, very slight growth. Penicillium developed abundantly on 100 per cent. The preservative up to 25 per cent concentration showed a decided stimulating effect.

The first concentration is based on the solution, as given above, which was prepared and submitted by the cooperator. Above 16½ per cent it was necessary to use a more concentrated solution, and a strength six times the original formula was prepared.

Coal-tar creosote, grade C.

(Pl. I, figs. 5 to 9.)

[Laboratory sample No. 1074. Purchased from the Creosote Supply Co., Chalmette, La. Liquid at room temperature, 8.4 per cent water; specific gravity, 1.0483 at 60° C.; flash point, 93° C.; burning point, 100° C.; 11 per cent distills below 205° C.; 54.1 per cent distills below 275° C.; 74.1 per cent distills below 320° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).											
	Num-ber.	Dura-tion.		0.075	0.125	0.175	0.2	0.225	0.3	0.35	0.4	0.45	0.5	0.55 ¹	Check.
		<i>Weeks.</i>													
Fomes annosus.....	44	4 to 8	1	...	...	...	2	1	1	1	1	1	1	0	4
F. pinicola.....	21	4 to 6	1	3	2	1	1	0	...	...	...	...	...	...	4

¹ These values are based on gum-arabic emulsions. Later work, using the pure preservative, indicates that the toxic point may fall somewhat lower.

Fomes annosus: In 17 days the radial growth of the check reached about 40 mm.; 0.2 and 0.275 per cent showed initial growth only. In three to four weeks, 0.2 per cent showed 10 mm.; 0.25 to 0.5 per cent, 2 to 3 mm. In six weeks, 0.525 per cent showed only initial growth. In seven weeks, 0.5 and 0.525 per cent reached 2 to 9 mm. The growth on the toxic media was about the same in appearance as on the check.

Fomes pinicola: In two weeks the radial growth of the check reached about 40 mm.; 0.075 per cent, 3 mm.; no growth above this point. In four weeks, 0.075 per cent showed 25 mm.; 0.1 per cent, 13 mm.; 0.15 per cent, 6 mm. After five weeks, 0.175 and 0.2 per cent reached 3 mm.; above this point all growth was inhibited. The growth on the toxic media was dull white, with a crinkled edge.

Coal-tar creosote, Fraction I.

(Pl. II, figs. 10 and 11.)

[Laboratory sample No. 1094. Cooperator, Somet-Solvay Co., Ensley, Ala. Light liquid at room temperature; specific gravity, 0.934 at 60° C.; flash point, 62° C.; burning point, 69° C.; 78.3 per cent distills below 215° C.]

Fungus.	Tests,		Times killing point ver- ified.	Concentration of the preservative (per cent).					
	Num- ber.	Dura- tion.		0.2	0.225	0.25	0.275	0.3	Check.
Fomes annosus.....	33	Weeks. 4 to 6	3	4	4	2	1	0	4
F. pinicola.....	13	4 to 6	1	4	0	.....	.....	.....	4

Fomes annosus: In 10 to 14 days the radial growth of the check reached 20 mm.; 0.2 to 0.25 per cent, from 1 to 4 mm. In four weeks, 0.2 to 0.225 per cent reached 30 mm.; 0.25 to 0.275 per cent, from 7 to 10 mm.; no growth at 0.3 per cent. The toxic cultures produced a thin, stringy growth.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; 0.2 per cent, 1 mm. In four weeks, 0.2 per cent reached 40 mm.; no growth above this point. The toxic cultures produced a fluffy white growth, similar in appearance to that on the check.

Coal-tar creosote, Fraction II.

(Pl. II, figs. 12 and 13.)

[Laboratory sample No. 1106. Cooperator, Semet-Solvay Co., Ensley, Ala. Naphthalene odor; nearly solid at room temperature; specific gravity, 1.003 at 60° C.; flash point, 79° C.; burning point, 85° C.; 9 per cent distills below 205° C.; 95.9 per cent distills below 287° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).						
	Number.	Duration.		0.1	0.125	0.15	0.175	0.2	0.225	Check.
<i>Fomes annosus</i>	20	Weeks. 5 to 9	1	-----	3	2	1	1	0	4
<i>F. pinicola</i>	18	4 to 5	2	4	4	0	-----	-----	-----	4

Fomes annosus: In two weeks the radial growth of the check reached 20 mm.; no growth on 0.15 per cent and above. In four weeks, no growth on 0.225 per cent. In six weeks, 0.15 per cent reached 12 mm.; 0.2 per cent, 6 mm.; no growth on 0.225 per cent. The growth on the toxic media was compact and creamy in color.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; no growth on 0.125 per cent. In four weeks 0.1 and 0.125 per cent reached 40 mm.; no growth above this point. The growth on the toxic media was a dingy white and less fluffy than that on the check.

Coal-tar creosote, Fraction III.

(Pl. III, fig. 30.)

[Laboratory sample No. 1107. Cooperator, Semet-Solvay Co., Ensley, Ala. Liquid at room temperature; specific gravity, 1.045 at 60° C.; flash point, 103° C.; burning point, 110° C.; 0.9 per cent distills below 215° C.; 4.7 per cent distills below 275° C.; fraction from 170° to 245° C. more or less solid with naphthalene.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).								
	Number.	Duration.		0.05	0.075	0.1	0.125	0.15	0.2	0.25	0.3	0.325 ¹
<i>Fomes annosus</i>	60	Weeks. 4 to 12	2	-----	-----	-----	-----	1	1	1	1	0
<i>F. pinicola</i>	14	4 to 7	1	3	2	1	0	-----	-----	-----	-----	-----

¹ The radial growth of *Fomes annosus* on concentrations above 0.2 per cent is very slight, usually not exceeding 1 mm., and the actual toxic point is difficult to locate. It lies between 0.25 and 0.35 per cent.

Fomes annosus: In 19 days the radial growth of the check reached 40 mm.; 0.15 and 0.175 per cent, 1 or 2 mm. In five to six weeks 0.3 per cent showed 1 mm. and lower concentrations 1 to 5 mm. The growth on the toxic media was creamy and slightly lighter than that on the check.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm. In about one month 0.05 per cent showed 3 mm.; 0.075 per cent, 2 mm. In about seven weeks 0.1 per cent showed initial growth; lower concentrations from 16 to 23 mm. The growth on the toxic media was a fluffy white on the lower concentrations; denser on 0.1 per cent.

Coal-tar creosote, Fraction IV.

(Pl. II, figs. 14 to 19.)

[Laboratory sample No. 1108. Cooperator, Semet-Solvay Co., Ensley, Ala. Liquid at room temperature; specific gravity, 1.088 at 60° C.; flash point, 130° C.; burning point, 136° C.; 0.9 per cent distills below 245° C.; 54.3 per cent distills below 320° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).											
	Num- ber.	Dura- tion.		0.025	0.05	0.075	0.1	0.125	0.2	0.9	1	2	3	3.3 ¹	Check.
		Weeks.													
Fomes annosus.....	75	5 to 12	1	---	---	---	---	---	2	2	1	1	1	0	4
F. pinicola.....	23	5 to 8	1	3	2	2	1	0	---	---	---	---	---	---	4

¹ The growth of *Fomes annosus* on concentrations above 2 per cent is very slight, usually not exceeding 1 mm. in six weeks, and the actual toxic point is difficult to locate. It lies between 2.5 and 3.5 per cent.

Fomes annosus: In 12 days, the radial growth of the check reached 25 mm.; very slight growth on 0.2 to 0.5 per cent. In 18 days, 0.8 to 3 per cent reached 1 to 4 mm. In four weeks, 1.25 to 3 per cent reached 1 to 5 mm. The growth on the toxic media was usually darker than on the check.

Fomes pinicola: In two weeks, the radial growth of the check reached 40 mm.; no growth on 0.025 per cent. In four weeks, 0.025 per cent showed 2 mm.; no growth on higher concentrations. In eight weeks, 0.025 per cent reached 25 mm.; 0.05 per cent, 15 mm.; 0.075 per cent, 10 mm.; 0.1 per cent, 2 mm.; no growth above this point. The growth on the toxic cultures was dull, compact, and crinkled.

Coal-tar creosote, Fraction V.

(Pl. II, figs. 21 to 24.)

[Laboratory sample No. 1109. Cooperator, Semet-Solvay Co., Ensley, Ala. Heavy, tarry liquid; specific gravity, 1.150 at 60° C.; flash point, 172° C.; burning point, 178° C.; 10.1 per cent distills below 320° C.; 63.3 per cent distills below 380° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).										Check.
	Num-ber.	Dura-tion.		0.1	0.5	1	7	7.8	8	30	33 ¹	---	---	
<i>Fomes annosus</i>	42	Weeks. 4 to 9	0	4	3	2	2	---	1	1	0	---	---	4
<i>F. pinicola</i>	30	4 to 8	0	---	---	2	1	0	---	---	---	---	---	4

¹ These values are based on gum-arabic emulsions.

Fomes annosus: In 10 to 14 days, the radial growth of the check reached about 40 mm.; 5.5 to 30 per cent showed 1 to 4 mm. In four weeks, 5.5 to 7.5 per cent reached 8 to 15 mm.; 15 and 25 per cent, 2 mm.; no growth on 20 per cent gum-arabic emulsion. The growth on the toxic media was dense and creamy on the lower concentrations; submerged at first on the higher concentrations.

Fomes pinicola: In two weeks, the radial growth of the check reached 40 mm.; in three weeks, 1 to 2 per cent showed initial growth; in four weeks, 3 to 6.5 per cent showed first growth; after eight weeks, 4.5 to 5 per cent reached 10 to 20 mm. The growth on the lower concentrations of the toxic media was white and fluffy; on the higher concentrations it was tawny and radiate, with a crinkled edge.

Avenarius carbolineum.

[Laboratory sample No. 1843. Cooperator, Carbolineum Wood Preserving Co., Milwaukee, Wis. Thick liquid at room temperature; specific gravity, 1.126 at 16.5° C.; flash point, 139° C.; burning point, 166° C.; 1.1 per cent distills below 215° C.; 6.1 per cent distills below 275° C.; 1.91 per cent tar acids.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).								
	Num-ber.	Dura-tion.		0.175	0.275	0.3	0.8	1	4	5	5.25	Check.
		Weeks.										
<i>Fomes annosus</i>	53	4 to 10	1	-----	-----	2	2	1	1	1	0	4
<i>F. pinicola</i>	18	5 to 6	2	1	1	0	-----	-----	-----	-----	-----	4

Fomes annosus: In 18 days, the radial growth of the check reached nearly 40 mm.; 0.3 per cent, 17 mm.; higher concentrations up to 4 per cent showed 1 to 6 mm. In four to six weeks, 5 per cent reached 1 mm. The growth on the toxic media was similar in appearance to that on the check.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; 0.175 per cent showed no growth. In four weeks, 0.175 to 0.275 per cent reached 1 mm. The growth on the toxic media was compact and darker than that on the check.

S. P. F. carbolineum.

(Pl. III, fig. 29.)

[Laboratory sample No. 1844. Cooperator, Bruno-Grosche & Co., New York, N. Y. Thick brown liquid, specific gravity, 1.127 at 16° C.; flash point, 133° C.; burning point, 157° C.; less than 9 per cent distills below 245° C.; about 30 per cent distills below 320° C.; 2.42 per cent tar acids.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).							
	Num-ber.	Dura-tion.		1	1.5	1.75	2	3	4	4.5 ¹	Check.
		Weeks.									
<i>Fomes annosus</i>	73	5 to 8	2	1	1	1	1	1	1	0	4

¹ The growth of *Fomes annosus* on concentrations above 3 per cent is very slight, usually not exceeding 1 mm. in six weeks, and the actual toxic point is difficult to locate. It lies between 4 and 5 per cent.

Fomes annosus: In four weeks the radial growth of the check reached about 40 mm.; 1 and 1.5 per cent, 1 mm. In six weeks, 1 and 1.5 per cent showed 5 mm.; 1.75 to 4 per cent, 1 to 5 mm. Tests were not made on concentrations below 1 per cent. The growth on the toxic media was quite similar in appearance to that on the check.

Water-gas tar distillate.

(Pl. III, figs. 27 and 28.)

[Laboratory sample No. 2235. Cooperator, United Gas Improvement Co., Philadelphia, Pa. Greenish brown liquid; specific gravity, 0.995 at 60° C.; flash point, 81° C.; burning point, 93° C.; 3.3 per cent distills below 180° C.; 61.7 per cent distills below 275° C.; 80.3 per cent distills below 320° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).									
	Num-ber.	Dura-tion.		0.1	0.2	0.3	0.35	0.4	0.45	0.5	0.6	0.65	Check.
		Weeks.											
<i>Fomes annosus</i>	58	5 to 8	0	4	3	2	2	1	1	1	1	0	4

Fomes annosus: In 12 days the radial growth of the check reached 15 mm.; 0.1 per cent, 2 mm. In three weeks, 0.1 per cent showed about 20 mm.; 0.2 per cent, 5 mm. In six weeks, 0.2 per cent reached 17 mm.; 0.25 per cent, 15 mm.; 0.3 per cent, 5 mm.; 0.35 to 0.6 per cent, from 1 to 12 mm. The growth on the toxic media was of a brighter creamy appearance than that on the check.

United Gas Improvement Co. 1.07 oil (water-gas tar distillate).

(Pl. III, figs. 25 and 26.)

[Laboratory sample No. 1101. Cooperator, United Gas Improvement Co., Philadelphia, Pa. Mobile, oily liquid, with kerosene odor; specific gravity, 1.058 at 60° C.; flash point, 48° C.; burning point, 65° C.; 9.04 per cent distills below 205° C.; 24.24 per cent distills below 315° C.; 67.9 per cent distills below 378° C.]

Fungus.	Tests.		Times killing point ver- ified.	Concentration of the preservative (per cent).										
	Num- ber.	Dura- tion.		0.1	3	3.5	5	6	6.5	10	25	30	40	Check.
Fomes annosus.....	31	Weeks. 4 to 8..	.....	4	4	3	2	.....	.....	2	1	1	1	4
F. pinicola.....	22	4 to 5..	.....	.....	2	2	2	2	1	.....	1	.....	1	4

Fomes annosus: In 10 to 14 days, the radial growth of the check reached 28 mm.; 40 and 50 per cent, 2 mm. In four to six weeks, 40 and 50 per cent showed nearly 10 mm. The growth on the toxic media appeared denser and of a brighter tan color than that on the check.

Fomes pinicola: In two weeks, the radial growth of the check reached almost 40 mm.; 3 to 29 per cent, 2 to 7 mm. In four to five weeks all concentrations between 3 and 40 per cent showed 2 to 15 mm. The growth on the toxic media appeared velvety, compact, and creamy, while that on the check was a fluffy white.

Wood tar (hardwood).

(Pl. IV, figs. 41-47.)

[Laboratory sample No. 1561. Cooperator, Marden, Orth & Hastings, Chicago, Ill. Black, viscous liquid, with pyrolygneous odor; specific gravity, 1.195 at 60° C.; flash point, 90° C.; contains 24 per cent water; 11.7 per cent distills below 105° C.; 50.9 per cent distills below 244° C.; decomposition occurs above 230°.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).							
	Num-ber.	Dura-tion.		0.2	0.5	0.7	0.75	0.9	1	1.25 ¹	Check.
<i>Fomes annosus</i>	50	Weeks. 4 to 6..	0	.....	4	.....	4	4	2	0	4
<i>F. pinicola</i>	30	4 to 5..	1	4	4	4	0	.....	.....	.....	4

¹ Based on gum-arabic emulsions.

Fomes annosus: In 9 to 10 days, the radial growth of the check reached 12 mm.; 0.5 to 0.8 per cent, 1 to 2 mm. In two to four weeks the check reached 40 mm. and concentrations up to 1 per cent showed 10 to 35 mm. The growth on the toxic media was dark creamy and somewhat denser than that on the check.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; 0.5 per cent, 10 mm.; no growth above this. In four to five weeks 0.2 to 0.7 per cent showed 40 mm.; 0.725 per cent, 10 mm.; no growth on higher concentrations. The growth on the toxic media was luxuriant, white, and fluffy.

Wood creosote (Douglas fir).

(Pl. III, figs. 32-37.)

[Laboratory sample No. 1099. Cooperator, Logged-Off Land Utilization Co., Seattle, Wash. Black liquid, with a strong pyroligneous odor; specific gravity, 1.052 at 60° C.; flash point, 45° C.; burning point, 85° C.; contains 8.35 per cent water; 7.55 per cent distills below 100° C.; 54.69 per cent distills below 245° C.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).									
	Num-ber.	Dura-tion.		0.1	0.125	0.15	0.2	0.25	0.4	0.45	0.6	0.65 ¹	Check.
		<i>Weeks.</i>											
<i>Fomes annosus</i>	55	4 to 7	0	4	-----	3	3	2	2	1	1	0	4
<i>F. pinicola</i>	26	4 to 6	0	4	4	4	0	-----	-----	-----	-----	-----	4

¹ These values are based on gum-arabic emulsions.

Fomes annosus: In 11 days the radial growth of the check reached 25 mm.; 0.15 to 0.30 per cent reached 3 to 6 mm. In 15 days, 0.1 per cent showed 30 mm. In four weeks, 0.15 to 0.30 per cent reached 18 to 28 mm. Usually, from four to six weeks were required for initial growth on 0.6 to 0.625 per cent. The growth on the toxic media was dense, dark creamy, occasionally zonate.

Fomes pinicola: In eight days the radial growth of the check reached 15 mm.; 0.025 to 0.075 per cent, 11 to 20 mm. In three weeks, 0.025 to 0.1 per cent covered the plates; 0.125 per cent reached 17 mm.; 0.15 per cent 4 mm. In 34 days the initial growth appeared on 0.175 per cent. The growth on the toxic media up to 0.125 per cent was white and luxuriant, exceeding that on the check.

Cresol calcium.

(Pl. III, figs. 38 and 39.)

[Laboratory sample No. 2086. Cooperator, Blagden, Waugh & Co., London, England.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).		
	Number.	Duration.		0.14	0.28	Check.
		<i>Weeks.</i>				
<i>Fomes annosus</i>	8	4 to 7	1	4	0	4

Fomes annosus: In about two weeks the radial growth of the check reached 20 mm.; 0.14 per cent, 3 mm. After three weeks the check showed 30 mm.; 0.14 per cent, 11 mm. After six weeks, 0.14 per cent reached 30 mm.; no growth on 0.28 per cent. The growth on the toxic media occurred in alternating light and dark zones.

A diversion from the usual method of weighing the preservative was necessary with this substance, since on sterilizing at 100° C. the preservative would form a hard crust on the sides of the bottles. To obviate this difficulty, the average weight of a drop from a small pipette was obtained (four tests). This was found to be 28 milligrams, the drops varying not over 2 or 3 milligrams. The preservative was then added directly to the media bottles in quantities of one, two, three, or four drops, the killing point lying between one and two drops, which corresponds to 0.14 and 0.28 per cent, respectively.

Copperized oil.

(Pl. IV, figs. 49 to 51.)

[Laboratory sample No. 1005. Cooperator, Ellis-Foster Co., New York, N. Y. Probably a crude petroleum containing a slight amount of copper and sufficient vegetable oil to form a homogeneous solution; specific gravity, 0.937 at 25° C.; flash point, 125° C.; burning point, 164° C.; less than 0.2 per cent distills below 215° C.; 30.2 per cent distills below 320° C.; about 80 per cent distills below 360° C.; copper content, 0.34 per cent.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).							Check.
	Num-ber.	Duration.		3	5	15	30	33	36	40	
		<i>Weeks.</i>									
<i>Fomes annosus</i>	40	4 to 9	1	4	4	3	2	2	2	0	4
<i>F. pinicola</i>	25	4 to 6	1	4	4	4	.....	.....	.....	4	4

Fomes annosus: In 18 to 22 days the radial growth of the check reached 40 mm.; the toxic concentrations up to 6.25 per cent showed the same growth, except that the check was denser. In about three weeks 15 to 30 per cent reached 1 to 11 mm. In nine weeks, 30, 33, and 36 per cent showed 12 to 20 mm. On the less toxic media alternating zones of lighter superficial growth and darker submerged growth occurred. On the high concentrations either a black submerged growth or a light-brown superficial growth appeared.

Fomes pinicola: In two weeks the radial growth of the check reached 40 mm.; 15 to 26 per cent, 20 to 27 mm.; 40 per cent, 2 mm. In six weeks all concentrations up to 40 per cent reached about 40 mm. The growth on the toxic media was fluffy, but darker than that on the check.

None-Such Special.

(Pl. IV, fig. 52.)

[Laboratory sample No. 2696. Cooperator, George M. Saums Co., Trenton, N. J. Yellow, oily liquid with strong varnish or paint odor; claimed by the manufacturers to waterproof and give a hard finish to timber, as well as prevent or stop decay; chemical composition unknown to us.]

Fungus.	Tests.		Times killing point verified.	Concentration of the preservative (per cent).							Check.
	Num-ber.	Duration.		1	5	15	25	30	35	40	
		<i>Weeks.</i>									
<i>Fomes annosus</i>	28	4	.....	4	4	4	4	4	4	4	4
<i>F. pinicola</i>	29	3 to 4	.....	4	4	4	4	4	4	.....	4

Fomes annosus: In 10 to 14 days the radial growth of the check reached 20 mm.; concentrations from 5 to 45 per cent showed approximately 40 mm. The preservative appears to exert a nutritive or stimulative effect, rather than any toxic action, although the fungus will not grow on the pure preservative. The growth on the treated media is dark and submerged, rising to the surface later to form a very dense creamy mycelium.

Fomes pinicola: In eight days the radial growth of the check reached about 30 mm.; 0.25 to 3 per cent, 15 to 20 mm. In two to three weeks 35 to 50 per cent showed 20 to 40 mm. The growth on all concentrations up to 50 per cent almost equaled that on the check.

DISCUSSION OF TESTS.

Table II gives the results of investigations in our laboratory in the use of such preservatives as have been sufficiently checked to permit statements regarding their toxicity to the fungi noted under

the test conditions outlined. In this table the preservatives are arranged in the order of their toxicity, beginning with the most toxic.

TABLE II.—*Killing point of Fomes annosus and F. pinicola for the various preservatives, compared with coal-tar creosote, No. 1074, and zinc chlorid, No. 2259.*

[Results marked with an asterisk (*) were not checked in duplicate, but they are approximately correct.]

Fungus and preservative.	Killing point.		Ratio to creosote.	Ratio to zinc chlorid.
	Per cent.	Pounds per cubic foot.		
<i>Fomes annosus</i> (creosote killing point, 0.55 per cent; zinc-chlorid killing point, 0.5 per cent):				
Coal-tar creosote, Fraction II.....	0.225	0.140	2.5	2.2
Sodium fluorid.....	.25	.156	2.2	2
Cresol calcium I.....	0.14-.28	0.087-.175	3.9-1.9	3.6-1.8
Coal-tar creosote, Fraction I.....	.30	.187	1.8	1.7
Coal-tar creosote, Fraction III.....	*.325	.203	1.7	1.5
Zinc chlorid.....	.50	.312	1.1	1
Coal-tar creosote, grade C.....	.55	.343	1	.91
Water-gas tar distillate No. 2235 (specific gravity 0.995)...	*.65	.405	.84	.76
Wood creosote (Douglas fir).....	*.65	.405	.84	.76
Wood tar (hardwood).....	*1.25	.78	.44	.40
Coal-tar creosote, Fraction IV.....	*3.30	2.06	.16	.15
S. P. F. carbolineum.....	4.5	2.8	.12	.11
Avenarius carbolineum.....	5.25	3.27	.104	.095
Coal-tar creosote, Fraction V.....	*33	20.59	.017	.015
Copperized oil.....	40	25	.014	.013
United Gas Improvement Co. 1.07 oil, No. 1101.....	40+	25+	.014-	.013-
None-Such Special.....	40+	25+	.014-	.012-
Sapwood antiseptic.....	75+	-----	.007-	.007
<i>Fomes pinicola</i> (creosote killing point, 0.225 per cent; zinc-chlorid killing point, 0.75 per cent):				
Coal-tar creosote, Fraction III.....	.125	.078	1.8	6
Coal-tar creosote, Fraction IV.....	*.125	.078	1.8	6
Coal-tar creosote, Fraction II.....	.15	.094	1.5	5
Sodium fluorid.....	.15	.094	1.5	5
Wood creosote (Douglas fir).....	*.20	.125	1.12	3.8
Coal-tar creosote, Fraction I.....	.225	.140	1	3.3
Coal-tar creosote, grade C.....	.225	.140	1	3.3
Avenarius carbolineum.....	3.30	.187	.75	2.5
Zinc chlorid.....	.75	.468	.30	1
Wood tar (hardwood).....	.75	.468	.30	1
Coal-tar creosote, Fraction V.....	*7.8	4.87	.029	.096
Copperized oil.....	40+	25+	.0056-	.019-
United Gas Improvement Co. 1.07 oil, No. 1101.....	40+	25+	.0056-	.019-
None-Such Special.....	50+	31.2+	.0045-	.0015-

¹ Killing point lies between the limits given (1 and 2 drops of the preservative in 20 c. c. of the medium).

Table II shows that of the 18 preservatives tested against *Fomes annosus* 6 totally inhibit growth at or below 0.5 per cent, 5 between 0.5 and 3.5 per cent, 1 at 4.5 per cent, 1 at 5.25 per cent, and the remaining 5 show extremely low toxic properties, requiring from 33 to 75 per cent.

Sodium fluorid is particularly toxic, being slightly more than twice as effective as zinc chlorid.

Cresol calcium in these tests shows a high toxicity, and the poor results reported against it in service tests¹ are apparently due to a change in chemical constitution or to leaching, which did not take place under our method of testing.

¹ Unpublished report, Forest-Products Laboratory.

The three lower boiling fractions of coal-tar creosote are highly toxic, exceeding the creosote itself. Fraction IV is only about one-sixth as toxic as creosote. Fraction V, consisting of the last heavy residues, of which only 10 per cent distills below 320° C., is extremely low in toxicity, with a killing concentration of about 33 per cent.

Wood creosote, derived from the destructive distillation of Douglas fir, compares very favorably with coal-tar creosote, notwithstanding its water content of over 8 per cent.

Hardwood tar shows moderate antiseptic properties, proving about one-half as toxic as the softwood creosote.

The two carbolineums are much less toxic than the creosotes tested.

Water-gas tar distillate of low specific gravity appears to be slightly less toxic than coal-tar creosote, while the heavier distillate, represented by United Gas Improvement Co. 1.07 oil, is so low in toxic properties as to appear to be of little value in wood preservation.

The secret product None-Such Special appears to be more nutrient than antiseptic to fungi, so far as these tests indicate; however, the physical properties of the substance when injected into wood may be such as to exclude fungous growth and thus to substantiate the claims made for it. Durability tests on treated wood are highly desired.

Zinc chlorid has a killing point almost identical with coal-tar creosote.

Table II also shows that of 14 preservatives tested against *Fomes pinicola* 8 totally inhibit growth below 0.5 per cent, 2 between 0.5 and 1 per cent, 1 at about 7.8 per cent, and the remaining 3 require over 40 per cent.

Sodium fluorid and coal-tar creosote Fractions II, III, and IV are all extremely toxic to this fungus, the killing points being almost identical.

Coal-tar creosote Fraction I and wood creosote are about three-fourths as toxic as the above; Avenarius carbolineum is about one-half as toxic.

Zinc chlorid in the *Fomes pinicola* list stands only tenth in efficiency, whereas in the *F. annosus* list it stands in fifth place.

The last four preservatives show very low antiseptic properties toward *Fomes pinicola*, as they did toward *F. annosus*.

By comparing the behavior of the two fungi toward the same chemical substances a marked difference will be observed. With the exception of zinc chlorid and copperized oil, *Fomes annosus* is a far more resistant organism than *F. pinicola*, the ratio running as high as 26 to 1 in the case of Fraction IV of coal-tar creosote.

It has often been noted during the course of the experiments that *Fomes annosus*, after a considerable lapse of time, can accommodate itself to rather high concentrations of certain preservatives. Its

normal growth is also relatively slow as compared with that of the other organism. Sometimes on high concentrations of toxic media the fungus would remain dormant from four to seven weeks and then begin a slow development. For this reason it has been difficult in many cases to find the exact inhibition point of a preservative without carrying out a large number of long-continued tests.

On the other hand, *Fomes pinicola* seems rather sensitive to slight changes in concentration, and one can usually judge within a month whether the fungus will develop.

The difference in behavior between these two organisms shows how very necessary it is to make only qualified statements when discussing the relative toxicity of preservatives toward fungi. We have at present no satisfactory way of predicting, except by trial, how a given preservative will react on different organisms.

A direct comparison of toxicities, as given in Table II, shows that in many cases essentially the same order holds, but there are several exceptions, Fractions I and IV of coal-tar creosote and zinc chlorid being the most conspicuous.

In Table III the oils used are grouped according to their nature, in order to show a direct comparison between wood tar, coal tar, water-gas tar, and petroleum products.

TABLE III.—List of wood-preserving oils tested, showing relation between their specific gravities, boiling points, and toxic properties.

[Results marked with an asterisk (*) are approximately correct.]

Preservative.	Specific gravity. ¹	Percentage distilling below—							Killing point (per cent).	
		180° C.	215° C.	245° C.	275° C.	305° C.	320° C.	360° C.	Fomes annosus.	Fomes pinicola.
Wood tar (hardwood).....	1.195	*27	*31	51	.....	.....	.....	.....	*1.25	0.75
Wood creosote (Douglas fir).....	1.052	*16	*31	54.7	.....	.....	.....	.....	*,.65	*,.20
United Gas Improvement Co. 1.07 oil, No. 1101.....	1.058	*7	*10	.....	16.3	*22	*27	56.4	40+	40+
Water-gas tar distillate No. 2235.....	.995	3.3	12.8	37.7	61.7	75.3	80.3	.....	*,.65	.....
Coal-tar creosote:										
Grade C.....	1.048	4.8	17.8	44.4	54.1	67.2	74.1	.....	.55	.225
Fraction I.....	.934	35.1	78.3	.....	.....	.....	.....	.....	.30	.225
Fraction II.....	1.003	*2-3	30	*80	*92	.....	.....	.....	.....	.....
Fraction III.....	1.045	.....	.9	16.2	49.2	77.7	85	.....	*,.325	*,.125
Fraction IV.....	1.088	.....	.....	.9	4.7	38.5	54.3	.....	*3.30	*,.125
Fraction V.....	1.150	.....	.....	.....	.....	4.1	10.1	48.7	*33	*7.8
Avenarius carbolineum (sp. gr. at 16.5° C.).....	1.126	.....	1.1	2.6	6.1	16.4	*29	.....	5.25	.30
S. P. F. carbolineum (sp. gr. at 16° C.).....	1.127	.....	.....	*9	.....	.....	*30	.....	4.5	.....
Copperized oil (sp. gr. at 25° C.).....	.937	.....	*,.2	*3	*10	*22	30.2	*80	40	40+

¹ At 60° C. except as stated for the last three preservatives.

It is interesting to note that the wood-tar and low-boiling water-gas tar and coal-tar distillates tested show very similar toxic properties, while the carbolineums, which consist in the main of the high-boiling constituents of coal-tar creosote, in all cases proved much less toxic to the fungi used.

The toxicity of water-gas tar products is highly variable, much more so than commercial coal-tar products. By decreasing the specific gravity the toxicity rapidly increased. The writers do not wish it to be inferred, however, that this necessarily means that water-gas tar and coal-tar products will prove equally efficient under service conditions. The present results are merely suggestive.

The fractionization of coal-tar creosote gives some interesting data. In the case of *Fomes annosus* the three lower fractions proved considerably more toxic than the creosote itself. In the case of *F. pinicola* the four lower fractions were included. In the former case Fraction II gave the best results and in the latter the greater toxicity fell to Fractions III and IV. This indicates that the middle fractions are the most efficient, but to what group of substances the greater toxicity is due we are not yet prepared to state. The work of other investigators with naphthalene, which is one of the principal constituents of Fraction II, would seem at least to militate against this substance.

The high-boiling carbolineums, which approach Fraction IV in their physical and chemical properties, likewise approach it in their toxic properties.

While the higher boiling constituents proved to be less toxic than the lower boiling ones, their greater permanence in wood under service conditions may at least partially offset the lessened toxic efficiency.

The poor showing made by copperized oil against both fungi indicates that adding small amounts of copper in this form to low-toxic petroleum or vegetable oils will produce a mixture of doubtful fungicidal value.

TOXICITY TO FUNGI OF CERTAIN OF THE MORE IMPORTANT PRESERVATIVES.

In order to bring together in convenient form for comparison the results secured by various investigators in the use of certain important preservative substances, as well as those originating in our own laboratory upon the preservatives mentioned, Table IV has been prepared, indicating the salient features of such tests.

In making comparisons, the sources of error as well as the degree of refinement which the figures represent, should be fully considered.

TABLE IV.—*Toxicity of various preservatives to certain wood-destroying and other fungi.*

Toxic substance.	Organism.	Toxic point.	Culture medium.	Duration of test.	Investigator.
A.—INORGANIC COMPOUNDS.					
Ammonium chromate $[(\text{NH}_4)_2\text{CrO}_4]$.	Coniophora cerebella.	<i>Per cent.</i> Under 1.....	Agar....	8 to 10 days.	Falek.
Ammonium fluorid $[\text{NH}_4\text{F}]$, neutral.	do.....	Under 0.1....	do.....	do.....	Do.

TABLE IV.—*Toxicity of various preservatives to certain wood-destroying and other fungi—Continued.*

Toxic substance.	Organism.	Toxic point.	Culture medium.	Duration of test.	Investigator.
A.—INORGANIC COMPOUNDS—CON.					
Ammonium fluorid.....	Coniophora cerebella.	<i>Per cent.</i> 0.123.....	Gelatin	4 weeks.....	Netzs.
Copper fluorid [CuF ₂ +2H ₂ O], pure.	do.	Under 0.1....	Agar....	8 to 10 days.	Falck.
Copper silico-fluorid [CuSiF ₆], pure.	do.	Under 0.05....	do.	do.	Do.
Copper sulphate [CuSO ₄ +5H ₂ O].	do.	Under 1.....	do.	do.	Do.
Copper sulphate.....	Molds.	3 to 5.....	Gelatin	14 days.....	Malenković.
Ferric fluorid [FeF ₃].	Coniophora cerebella.	0.132.....	do.	4 weeks.....	Netzs.
Ferric sulphate [FeSO ₄ +7H ₂ O].	do.	Under 2.....	Agar....	8 to 10 days.	Falck.
Ferrous fluorid [FeF ₂].	do.	0.155.....	Gelatin	4 weeks.....	Netzs.
Hydrofluoric acid [HF], 100 per cent.	do.	Under 0.01....	Agar....	8 to 10 days.	Falck.
Hydrofluoric acid.....	do.	0.05.....	Gelatin	4 weeks.....	Netzs.
Hydrofluorsilicic acid [H ₂ SiF ₃].	do.	Under 0.05....	Agar....	8 to 10 days.	Falck.
Hydrofluorsilicic acid.....	do.	0.120.....	Gelatin	4 weeks.....	Netzs.
Magnesium silicofluorid [MgSiF ₆ +6H ₂ O], 95 per cent.	do.	Under 0.067.	Agar....	8 to 10 days.	Falck.
Magnesium sulphate [MgSO ₄ +7H ₂ O].	do.	Over 16.....	do.	do.	Do.
Mercuric chlorid [HgCl ₂].	do.	Under 0.1....	do.	do.	Do.
Potassium fluorid [KF], pure.	do.	Under 0.05....	do.	do.	Do.
Potassium fluorid.....	do.	0.192.....	Gelatin	4 weeks.....	Netzs.
Sodium chlorid [NaCl].....	do.	Under 10.....	Agar....	8 to 10 days.	Falck.
Sodium chlorid.....	Mold.	Over 5.....	Gelatin	14 days.....	Malenković.
Sodium fluorid [NaF].....	do.	2.....	do.	do.	Do.
Sodium fluorid, tech. refined.	Coniophora cerebella.	Under 0.1....	Agar....	8 to 10 days.	Falck.
Sodium fluorid.....	do.	0.139.....	Gelatin	4 weeks.....	Netzs.
Sodium fluorid, tech.....	Fomes annosus.....	0.25.....	Agar....	do.	Humphrey and Fleming.
Do.	F. pinicola.	0.15.....	do.	5 to 7 weeks.	Do.
Sodium carbonate [Na ₂ CO ₃].	Coniophora cerebella.	Under 0.125.	do.	10 days.....	Rumbold.
Sodium silico-fluorid [Na ₂ SiF ₆], about 100 per cent.	do.	Under 0.1....	do.	8 to 10 days.	Falck.
Sodium silico-fluorid.....	do.	0.208.....	Gelatin	4 weeks.....	Netzs.
Zinc chlorid [ZnCl ₂].....	do.	Under 0.5....	Agar....	8 to 10 days.	Falck.
Zinc chlorid.....	do.	Between 1 and 2.	do.	8 days.....	Rumbold.
Do.	Lenzites sepiaria.	do.	do.	do.	Do.
Do.	Polystictus hirsutus.	do.	do.	do.	Do.
Do.	P. versicolor.	Over 2.....	do.	do.	Do.
Zinc chlorid, commercial..	Fomes pinicola.....	0.75.....	do.	4 to 8 weeks..	Humphrey and Fleming.
Do.	F. annosus.....	0.5.....	do.	5 to 7 weeks..	Do.
Zinc fluorid [ZnF ₂].....	Coniophora cerebella.	0.186.....	Gelatin	4 weeks.....	Netzs.
Acid zinc fluorid, tech.	do.	Under 0.1....	Agar....	8 to 10 days.	Falck.
Acid zinc fluorid [ZnF ₂ -HF].	do.	0.130.....	Gelatin	4 weeks.....	Netzs.
Zinc silico-fluorid.....	do.	0.159.....	do.	do.	Do.
Zinc silico-fluorid [ZnSiF ₆ +6H ₂ O].	do.	Under 0.1....	Agar....	8 to 10 days.	Falck.
Zinc sulphate [ZnSO ₄ +7H ₂ O].	do.	Under 1.....	do.	do.	Do.
B.—ORGANIC COMPOUNDS.					
<i>(a) Benzol and phenol derivatives.</i>					
Anilin [C ₆ H ₅ NH ₂].....	Coniophora cerebella.	Under 1.....	Agar....	8 to 10 days.	Falck.
Cresol [C ₆ H ₄ CH ₃ OH].....	do.	Under 0.125.	do.	8 days.....	Rumbold.
Cresol.....	Lenzites sepiaria.	do.	do.	do.	Do.
Do.	Polystictus versicolor	do.	do.	do.	Do.
Do.	P. hirsutus.....	Under 0.25.	do.	do.	Do.
Cresol, pure.....	Penicillium.....	Under 0.05....	do.	4 weeks.....	J. M. Weiss.
Cresol calcium.....	Coniophora cerebella.	Between 1 and 2.	do.	8 days.....	Rumbold.
Do.	Lenzites sepiaria.....	Over 2.....	do.	do.	Do.
Do.	Polystictus versicolor	Between 1 and 2.	do.	do.	Do.

TABLE IV.—*Toxicity of various preservatives to certain wood-destroying and other fungi—Continued.*

Toxic substance.	Organism.	Toxic point.	Culture medium.	Duration of test.	Investigator.
B.—ORGANIC COMPOUNDS—continued.					
<i>(a) Benzol and phenol derivatives—Continued.</i>					
Cresol calcium.....	<i>P. hirsutus</i>	<i>Per cent.</i> Between 1 and 2.	Agar.....	8 days.....	Rumbold.
Do.....	<i>Fomes annosus</i>	Between 0.14 and 0.28.	do.....	4 to 7 weeks..	Humphrey and Fleming.
Dinitro-p-cresol [$C_6H_2(NO_2)_2CH_3OH$].	<i>Coniophora cerebella</i> .	Under 0.1.....	do.....	8 to 10 days..	Falck.
Sodium salt of—					
Dinitro-p-cresol, 21 per cent. ¹	do.....	Under 0.01.....	do.....	do.....	Do.
1:2 dinitro-o-cresol, 31 per cent. ¹	do.....	Under 0.003.....	do.....	do.....	Do.
4:6 dinitro-m-cresol, 59 per cent. ¹	do.....	Under 0.005.....	do.....	do.....	Do.
Gallic acid [$C_7H_5O_5 + H_2O$]	do.....	Under 2.....	do.....	do.....	Do.
Gallotannic acid [$C_{14}H_{10}O_4$].	do.....	Under 1.....	do.....	do.....	Do.
Phenol [C_6H_5OH].....	do.....	Under 0.1.....	do.....	do.....	Do.
Phenol, pure.....	<i>Penicillium</i>	0.15.....	do.....	4 weeks.....	J. M. Weiss.
O-nitrophenol [$C_6H_4NO_2OH$].	<i>Coniophora cerebella</i> .	Under 0.02.....	do.....	8 to 10 days..	Falck.
P-nitrophenol.....	do.....	Under 0.01.....	do.....	do.....	Do.
Sodium salt of—					
O-nitrophenol, 63 per cent. ¹	do.....	Under 0.013.....	do.....	do.....	Do.
P-nitrophenol, 60 per cent. ¹	do.....	Under 0.025.....	do.....	do.....	Do.
2:4 dinitrophenol [$C_6H_3(NO_2)_2OH$].	do.....	Under 0.01.....	do.....	do.....	Do.
2:4 dinitrophenol, 33 per cent. ¹	do.....	Under 0.003.....	do.....	do.....	Do.
Salicylic acid [$C_6H_4OH-COOH$].	do.....	Under 0.1.....	do.....	do.....	Do.
Sodium picrate [$C_6H_2(NO_2)_3ONa$], 40 per cent. ¹	do.....	Under 0.04.....	do.....	do.....	Do.
Thymol [$C_6H_3CH_3C_6H_7OH$].	do.....	Under 0.01.....	do.....	do.....	Do.
<i>(b) Tars and creosotes.</i>					
Coal-tar creosote:					
Straight run, American (sp. gr. 1.049 at 15.5° C.).	<i>Penicillium</i>	0.15.....	Agar.....	4 weeks.....	J. M. Weiss.
5 per cent gum-arabic emulsion.	<i>Polystictus versicolor</i> .	0.25–0.40.....	do.....	do.....	Dean and Downs.
German (sp. gr. 1.09 at 15° C.).	Molds.....	0.2.....	do.....	4 weeks.....	J. M. Weiss.
Sp. gr. 1.048 at 60° C..	<i>Fomes pinicola</i>	0.225.....	do.....	4 to 6 weeks..	Humphrey and Fleming.
5 per cent gum-arabic emulsion.	<i>F. annosus</i>	0.55.....	do.....	do.....	Do.
German (sp. gr. 1.062 at 38° C.).	<i>Coniophora cerebella</i> .	Under 0.125.....	do.....	8 days.....	Rumbold.
Do.....	<i>Lenzites sepiaria</i>	Under 0.125.....	do.....	do.....	Do.
Do.....	<i>Polystictus versicolor</i> .	Under 0.25.....	do.....	do.....	Do.
Do.....	<i>P. hirsutus</i>	Under 0.25.....	do.....	do.....	Do.
Carbolineum:					
Avenarius (sp. gr. 1.126 at 16.5° C.).	<i>Fomes annosus</i>	5.25.....	do.....	4 to 10 weeks..	Humphrey and Fleming.
Do.....	<i>F. pinicola</i>	0.30.....	do.....	5 to 6 weeks..	Do.
S. P. F. (sp. gr. 1.127 at 16° C.).	<i>F. annosus</i>	4.5.....	do.....	5 to 8 weeks..	Do.
Coal-tar creosote:					
With bases, acids, and solid hydrocarbons removed.	<i>Penicillium</i>	0.85.....	do.....	4 weeks.....	J. M. Weiss.
With 20 per cent tar acids added.	do.....	0.15.....	do.....	do.....	Do.
With 20 per cent pure naphthalene added.	do.....	0.95.....	do.....	do.....	Do.
With 5 per cent filtered tar added.	do.....	0.45.....	do.....	do.....	Do.

¹ Toxic value based on 100 per cent pure salt.

TABLE IV.—*Toxicity of various preservatives to certain wood-destroying and other fungi—Continued.*

Toxic substance.	Organism.	Toxic point.	Culture medium.	Duration of test.	Investigator.
B.—ORGANIC COMPOUNDS—continued.					
(b) <i>Tars and creosotes</i> —Continued.					
Coal-tar creosote—Contd. With 10 per cent filtered tar added.	Penicillium.....	<i>Per cent.</i> 0.30.....	Agar....	4 weeks....	J. M. Weiss.
With 20 per cent filtered tar added.	do.....	0.60.....	do.....	do.....	Do.
Coal tar (undistilled, sp. gr. 1.194 at 15.5° C.).	Molds.....	Between 1.5 and 2.	do.....	do.....	Do.
Coal-tar creosote: Fraction I (sp. gr. 0.934 at 60° C., 78.3 per cent distills below 215° C.).	Fomes annosus.....	0.30.....	do.....	4 to 6 weeks.	Humphrey and Fleming.
Do.....	F. pinicola.....	0.225.....	do.....	do.....	Do.
Fraction II (sp. gr. 1.003 at 60° C., 9 per cent distills below 205° C., 95.9 per cent below 287° C.).	F. annosus.....	0.225.....	do.....	5 to 9 weeks.	Do.
Do.....	F. pinicola.....	0.15.....	do.....	4 to 5 weeks.	Do.
Fraction III (sp. gr. 1.045 at 60° C., 73.7 per cent distills below 295° C.).	F. annosus.....	0.325.....	do.....	4 to 8 weeks.	Do.
Do.....	F. pinicola.....	0.125.....	do.....	4 to 7 weeks.	Do.
Fraction IV (sp. gr. 1.088 at 60° C., 54.3 per cent distills between 285° and 320° C.).	F. annosus.....	3.3.....	do.....	4 to 6 weeks.	Do.
Do.....	F. pinicola.....	0.125.....	do.....	5 to 8 weeks.	Do.
Fraction V (10 per cent distills above 320° C., 36.6 per cent hard residue).	F. annosus.....	33.....	do.....	4 to 6 weeks.	Do.
Do.....	F. pinicola.....	7.8.....	do.....	5 to 8 weeks.	Do.
Fraction below 235° C.	Penicillium.....	0.35.....	do.....	4 weeks.....	J. M. Weiss.
Fraction between 235°-272° C.	do.....	0.25.....	do.....	do.....	Do.
Fraction above 272° C.	do.....	Between 4 and 4.5.	do.....	do.....	Do.
Anthracene, pure.....	do.....	Above 10.....	do.....	do.....	Do.
Naphthalene, pure.....	do.....	Between 9 and 10.	do.....	do.....	Do.
Quinolin, pure.....	do.....	0.10.....	do.....	do.....	Do.
Paraffin, pure.....	do.....	Above 10.....	do.....	do.....	Do.
Water-gas tar distillate: Fraction between 170°-340° C.	Polystictus versicolor.....	0.40.....	do.....	do.....	Dean and Downs.
Fraction between 170°-315° C. (sp. gr. 1.024 at 15.5° C.).	Penicillium.....	2.....	do.....	4 weeks.....	J. M. Weiss.
Fraction between 210°-315° C. (sp. gr. 1.053 at 15.5° C.).	do.....	Above 10.....	do.....	do.....	Do.
United Gas Improvement Co. oil (sp. gr. 1.058 at 60° C.).	Fomes annosus.....	Above 40.....	do.....	4 to 8 weeks.	Humphrey and Fleming.
Do.....	F. pinicola.....	Above 40.....	do.....	4 to 5 weeks.	Do.
Sp. gr. 0.995 at 60° C.	F. annosus.....	About 0.65.....	do.....	5 to 8 weeks.	Do.
Wood creosote (softwood, sp. gr. 1.052 at 60° C., about 8 per cent H ₂ O).	do.....	0.65.....	do.....	4 to 7 weeks.	Do.
Do.....	F. pinicola.....	0.20.....	do.....	4 to 6 weeks.	Do.
Wood tar (hardwood, sp. gr. 1.195 at 60° C.).	F. annosus.....	1.25.....	do.....	do.....	Do.
Do.....	F. pinicola.....	0.75.....	do.....	4 to 5 weeks.	Do.
Semiasphaltic petroleum (sp. gr. 0.973 at 15.5° C.; distills above 315° C.).	Penicillium.....	Above 10.....	do.....	4 weeks.....	J. M. Weiss.

In conclusion, the writers wish to emphasize that any scale of toxicities derived from Petri-dish tests on the usual nutrient agar or

gelatin media, even when the tests are conducted under exactly similar conditions, do not necessarily represent the true relative toxic values of the different compounds, for the interaction between the toxic compounds, the nutrient substances contained in the media, and the plant protoplasm is variable and more or less specific for each combination.

Also, the reader should keep before him the fact that toxicity alone is not the sole criterion in judging the service value of a preservative, and a direct application of these data to that end would in many cases lead to very erroneous conclusions.

In many cases it is possible to overcome such unfavorable properties in a preservative as high solubility in water by placing the treated timber under conditions less exposed, and such timbers treated with soluble preservatives, such as sodium fluorid, zinc chlorid, and copper sulphate, should behave more or less according to the toxic ratios represented. The same should apply to oils of similar volatile and soluble properties placed under approximately similar service conditions.

Not all preservatives are adapted to the same uses, and in testing their service value these primary facts should be given full consideration. We have long been in the habit of taking as the standard test of the efficiency of a substance its ability to protect timber exposed to such extreme conditions as are railway ties, telephone poles, posts, exterior building timbers, etc. This standard is very often too severe, and for this reason preservatives should be grouped according to the conditions under which they are to be exposed.

SUMMARY.

A survey of the work of various investigators on the action of different toxic substances on the higher and lower forms of plant life discloses a marked difference in behavior. The action of toxic agents appears to be specific, being highly poisonous to certain organisms and only moderately so to others.

Very dilute concentrations ordinarily produce a stimulative effect.

Among the fungi, as a rule, the common molds are more resistant to poisons than the true wood-destroying fungi, and even among the latter group the different species show a great difference in susceptibility.

The chemical and physical composition of the media supporting the growth of the fungi determines, to a large extent, their development. The presence of certain kinds of insoluble matter or of such organic compounds as sugars and proteid materials, with which the toxic agents may possibly react, often introduces a considerable element of error when testing the toxic value of a substance by mixing it with nutrient agar or gelatin media.

Temperature is also an elemental factor in the growth of fungi, and there is an optimum for each organism, often lying within a very narrow range. The growth activities of fungi probably bear a close relation to the resistance offered toward toxic agents.

The toxic elements or radicals in a compound are often difficult to determine. In the case of heavy metallic salts, it is the metal ion; in the case of strong inorganic acids, the hydrogen ion is said to be the important element; in the fluorin compounds, fluorin is the determining agent; in the case of certain phenols, the introduction of halogen, alkyl, or nitro groups is said to increase toxicity. Even in the case of isomeric compounds the grouping of the radicals plays an important part.

The Petri-dish method of determining the toxicity of a substance offers a ready procedure which gives indicatory results in a short time. On account of certain sources of error, some inaccuracies must be admitted, although the methods employed by the writers obviate many of these.

The results of tests on 18 wood preservatives at the Forest-Products Laboratory, against two wood-destroying fungi, *Fomes annosus* Fr. and *F. pinicola* (Sw.) Fr., are given. The preservatives act in a considerably different manner on these two organisms, the former being, as a rule, far more resistant.

The tests show that for these two organisms the following quantities of preservative per cubic foot of culture medium used are sufficient to inhibit all growth:

FOR FOMES ANNOSUS.		FOR FOMES PINICOLA.	
	Pounds.		Pounds.
Coal-tar creosote, Fraction II	0.14	Coal-tar creosote:	
Sodium fluorid.....	.16	Fraction III.....	0.08
Cresol calcium.....	0.09- .18	Fraction IV.....	.08
Coal-tar creosote:		Fraction II.....	.09
Fraction I.....	.19	Sodium fluorid.....	.09
Fraction III.....	.20	Wood creosote.....	.13
Zinc chlorid.....	.31	Coal-tar creosote:	
Coal-tar creosote, grade C...	.34	Grade C.....	.14
Water-gas tar distillate (sp.		Fraction I.....	.14
gr. 0.995).....	.41	Avenarius carbolineum...	.19
Wood creosote.....	.41	Zinc chlorid.....	.47
Hardwood tar.....	.78	Hardwood tar.....	.47
Coal-tar creosote, Fraction IV	2.06	Coal-tar creosote, Fraction V	4.87
S. P. F. carbolineum.....	2.8	Copperized oil.....	Over 25
Avenarius carbolineum....	3.27	United Gas Improvement	
Coal-tar creosote, Fraction V.	20.59	Co., 1.07 oil.....	Over 25
Copperized oil.....	25	None-Such Special.....	Over 25
United Gas Improvement			
Co., 1.07 oil.....	Over 25		
None-Such Special.....	Over 25		
Sapwood antiseptic.....	Over 25		

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No. 247

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July 20, 1915.

(PROFESSIONAL PAPER.)

A DISEASE OF PINES CAUSED BY *CRONARTIUM* *PYRIFORME*.

By GEORGE G. HEDGCOCK, *Pathologist*, and WILLIAM H. LONG, *Forest Pathologist*,
Investigations in Forest Pathology.

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HISTORY OF THE FUNGUS.

In 1875 Peck (10)¹ described as a new species under the name *Peridermium pyriforme* a caulicolous or stem-inhabiting *Peridermium* with obovate to pyriform spores from a specimen collected by J. B. Ellis (No. 2040). In 1882 Ellis issued in his *North American Fungi* under No. 1021 a caulicolous *Peridermium* which he called "*Peridermium pyriforme* on small branches of *Pinus virginiana*," and in the Ellis Herbarium, now at the New York Botanical Garden is a specimen labeled "*Peridermium pyriforme* on small branches of *Pinus rigida*, Newfield, New Jersey, May, 1890." Both of these latter specimens appear to be *Peridermium comptoniae*; at any rate, neither of them is the true *P. pyriforme* originally described by Peck. Arthur and Kern (1) in 1906 described as *P. pyriforme* Peck what is now known as *P. comptoniae*.

In 1913 the writers received from Prof. E. Bethel a caulicolous species of *Peridermium* on *Pinus contorta*, which they described as a

¹ Reference is made by number to "Literature cited," p. 20.

NOTE.—This bulletin discusses an important disease of pines which is now for the first time fully described. It is intended for circulation among botanists, foresters, nurserymen, State inspectors, and horticulturists.

new species, *Peridermium betheli* (6). The type material *P. pyriforme* was not accessible at the time the article was prepared, as all of Peck's specimens were packed up and in transit from the old to the new quarters of the New York State Museum. The writers therefore had to depend upon Arthur and Kern's published statement concerning this species (1, p. 420). The spore measurements also of the typical *P. pyriforme* did not correspond, since the length of spores of the eastern species as given by Peck in his original description was too great. While this article by the writers (6) was in press, Arthur and Kern published an article (2) in which they discarded their earlier interpretation of *P. pyriforme* and admitted that there is a species of *Peridermium* with typical "pyriform, obovate, or oblong-pyriform spores," just as Peck had originally described it in 1875 (10), and that their original assignment of *P. pyriforme* Peck to what is now known as *P. comptoniae* was an error. They also suggested that the alternate stages of this *Peridermium* would probably be found on species of *Comandra*.

Orton and Adams (9), in 1914, published an article on *Peridermium* from Pennsylvania, in which they discussed *Peridermium comptoniae* and *P. pyriforme*. They described the finding of a caulicolous species of *Peridermium* at Charteroak, Huntingdon County, Pa., on the trunks of *Pinus pungens*, which proved to be the true *Peridermium pyriforme* of Peck. Subsequently *Cronartium comandrae* was found within 40 feet of the infected pines and the conclusion reached that this *Cronartium* is the alternate stage of *Peridermium pyriforme*. They also state that *P. betheli* is probably a synonym of *P. pyriforme*. In May, 1914, Arthur and Kern in a general discussion of the North American species of *Peridermium* inhabiting pines (3) gave the synonymy of *P. pyriforme*, a technical description, and an explanation of their change of opinion regarding the species.

In June, 1914, the writers published culture data (8) showing that successful sowings of the æciospores of *Peridermium pyriforme* had been made on *Comandra umbellata*, thus completing the life cycle of this interesting rust and proving that its alternate stage was the *Cronartium* found on *Comandra*.

MORPHOLOGY OF THE FUNGUS.

The macroscopic characters of *Peridermium pyriforme* are practically identical on all the hosts examined by the writers, but there are some differences in the microscopic characters, especially in the shape and size of the æciospores. This difference in size and shape of the spores may be due to the influence of the æcial host; that is, they may vary according to the species of *Pinus* which the *Peridermium* inhabits. In specimens of the rust on *Pinus contorta* (Pl. I,

fig. 4) from Colorado, some of the æciospores are very short and slightly acuminate, while many are ellipsoid or even globoid (Pl. I, fig. 3). In specimens on *Pinus pungens* from Pennsylvania many of the spores are nearly twice as long as those from *Pinus contorta*, the acumination is very marked, and the spores are rarely ellipsoid (Pl. I, fig. 2).

Peck's type material of *Peridermium pyrifforme* is in the New York State Museum, at Albany, N. Y. It consists of a split branch 4 cm. long, 1 cm. thick at one end and 0.5 cm. thick at the other; the weak, fragile peridia barely protrude beyond the bark. The split surface of the twig is glued to the yellow paper bearing one of the legends. The specimen is in fairly good condition and most of the essential characters, both macroscopic and microscopic, can be determined from it. What appears to be the other half of this specimen is at the New York Botanical Garden, Bronx Park, N. Y., but it is much insect eaten and but little can be determined from it.

The type material at Albany bears the following legends on the box: "*Peridermium pyrifforme*, Newfield, N. J. Ellis #2040." On the original wrapper is "*Peridermium pyrifforme* on pine limbs in the spring, Newfield, N. J. .0015-.0025. No. 2040 Ellis." This legend is in two parts. The name is in Peck's handwriting, with a drawing of a spore and size of spores in pencil, while the host, location, and number of the specimen are in ink and are in Ellis's handwriting. The word "type" is not in the original legend. The following is Peck's original description of *Peridermium pyrifforme* (10) and his remarks on the same:

Peridia erumpent, large, white when evacuated, the cells subrotund, with a paler margin, marked with radiating striations, spores obovate, pyriform, or oblong-pyriform, acuminate below, .0015-.0025 inch long.

Bark of pine branches. The specimen is labeled "Newfield, N. J.," but Mr. Ellis informs me that it may have been collected in Georgia and placed by accident among his New Jersey specimens.

In the dried specimens the peridia are mostly compressed, about one-fourth of an inch long, and scarcely exerted above the surface of the bark. The spores are pale yellow, but probably they are more highly colored when fresh. The acumination is generally acutely pointed, and it is sometimes so elongated as to make the spore appear clavate. It is one of the most distinctive features of the species.

SYNONYMY AND DESCRIPTION OF THE FUNGUS.

Cronartium pyrifforme (Peck) Hedgc. and Long, 1914, Alternate Stage of *Peridermium Pyrifforme*.

Cronartium asclepiadeum thesii Berk., 1845, in Lond. Jour. Bot., v. 4, p. 311.

Peridermium pyrifforme Peck, 1875, in Bul. Torrey Bot. Club, v. 6, No. 2, p. 13.

Caeoma comandrae Peck, 1884, in Bul. Torrey Bot. Club, v. 11, No. 5, p. 50.

Cronartium thesii (Berk.) Lagerh., 1895, in Tromsø Mus. Aarsh., v. 17, p. 94.

Peridermium betheli Hedgc. and Long, 1913, in Phytopathology, v. 3, No. 4, p. 251.

Pycnia unknown.

Æcia caulicolous, appearing on branches or trunks, forming lesions or fusiform swellings 2 to 30 cm. long (Pl. II, fig. 3); sori scattered or somewhat confluent in small groups, rounded or irregular, 2 to 6 mm. long by 2 to 4 mm. wide by 1 to 2 mm. high; peridium usually only slightly protruding from the bark, bladdery, subhemispherical, rupturing irregularly along the top and sides, without concolorous processes, about 2 cells thick, outer surface minutely and rather closely verrucose, inner surface also rather closely verrucose but with longer tubercles; peridial cells with a radially striate margin, not easily torn apart, those of the inner layer often irregularly compressed, walls thin, 2 to 4 μ in thickness, lumen large; cells in the upper portion of the peridium ovate, 15 to 20 by 22 to 42 μ , in the lower portion ellipsoid to ovate, 16 to 20 by 40 to 60 μ ; æciospores very variable in size and shape, subglobose, obovate, ellipsoid, pyriform or even subclavate on some hosts, more or less acuminate at the basal end, occasionally at both ends (Pl. I, figs. 1, 2, and 3), 15 to 27 by 25 to 74 μ , average for 160 æciospores 21.6 by 57.5 μ , walls colorless, thicker at both ends than in the middle, 2 to 4 μ thick, rather densely verrucose with small irregular tubercles which in narrow ellipsoid spores are often arranged in irregular almost parallel lines or with a ridgelike marking, which gives the surface a reticulate appearance, no smooth spot present; cell contents of the æciospores orange yellow when fresh.

Found on *Pinus contorta* Loud., *P. divaricata* (Ait.) Du Mont du Cours., *P. ponderosa* Laws., *P. ponderosa scopulorum* Sudw., *P. pungens* Michx., and *Pinus* sp.

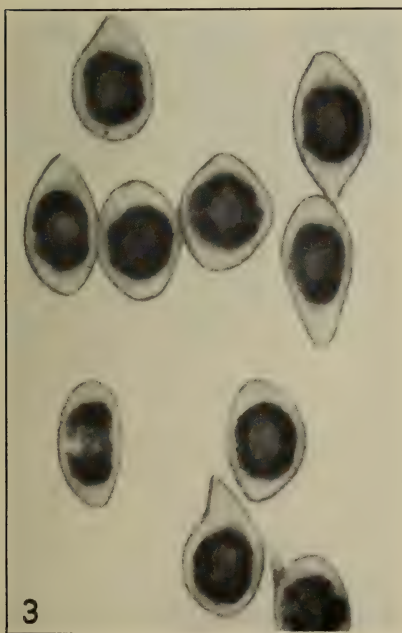
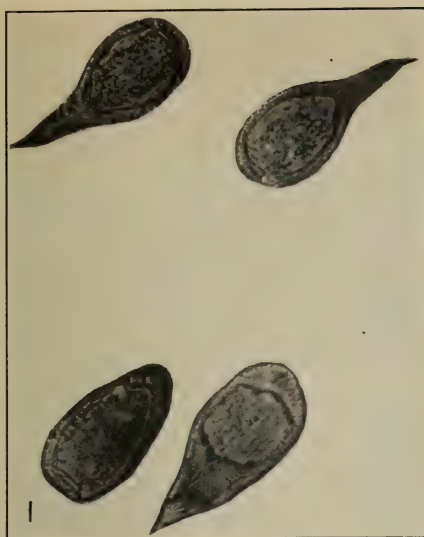
Uredinia amphigenous or hypophyllous,¹ scattered or densely gregarious, on pallid areas, pustular, 125 to 200 μ in diameter, dehiscent by a central opening or pore; peridium delicate; urediniospores broadly elliptical to globose, 16 to 21 by 19 to 25 μ , average for 10 spores 17.8 by 20 μ , walls nearly colorless and sparsely but minutely echinulate, 1.5 to 2 μ thick.

Telial columns amphigenous or hypophyllous,¹ caulicolous, cylindrical, 80 to 115 μ thick, about 1 mm. in length; teliospores oblong to cylindrical, obtuse to truncate at one or both ends, 12 to 16 by 28 to 40 μ , average for 10 spores 14 by 32.7 μ , walls smooth, nearly colorless.

Found on *Comandra pallida* A. DC., *C. umbellata* (L.) Nutt., and *C. richardsiana* Fernald (?).

In the preceding description by the junior writer, the æcial characters (Peridermium) are taken from the specimens named in Table II on *Pinus contorta*, *P. ponderosa*, *P. ponderosa scopulorum*, and *P. pungens*. The uredinial and telial characters (Cronartium) are

¹ Amphigenous on *Comandra pallida*, hypophyllous on *Comandra umbellata*.



ÆCIOSPORES OF CRONARTIUM PYRIFORME AND A TWIG OF PINUS CONTORTA.

FIG. 1.—Æciospores of *Cronartium pyriforme*, from the type specimen on *Pinus* sp. at Albany, N. Y. (Microphotograph.) FIG. 2.—Æciospores of *Cronartium pyriforme* from *Pinus pungens*, collected near Greenwood Furnace, Pa. (Microphotograph.) These closely resemble the type. FIG. 3.—Æciospores of *Cronartium pyriforme* from *Pinus contorta*, near Eldorado Springs, Colo., from the same tree as the type of *Peridermium betheli* (microphotograph), showing the variation in the shape of the spores on this pine from those of the type specimen in figure 1. FIG. 4.—A twig of *Pinus contorta*, showing the æcia and peridia of the fungus *Peridermium pyriforme* (*P. betheli*) on a slightly swollen portion. (About natural size.)



INJURIES TO PINES PRODUCED BY CRONARTIUM PYRIFORME.

FIG. 1.—A slight hypertrophy of the trunk of a small tree of *Pinus pungens* produced by the æcia of *Cronartium pyrifforme*. (About one-third natural size.) FIG. 2.—Openings produced by the rupturing of the bark of *Pinus pungens* by the maturing of the æcia of *Cronartium (Peridermium) pyrifforme*. (About one-third natural size.) FIG. 3.—A twig of *Pinus contorta*, showing a fusiform swelling produced by *Cronartium (Peridermium) pyrifforme* on this species of tree. Similar fusiform swellings are produced by the fungus on *Pinus ponderosa*. (About one-half natural size.)

taken from specimens of the fungus on leaves of *Comandra umbellata* obtained by inoculations with æciospores from *Pinus pungens* from Greenwood Furnace, Pa.

INOCULATION EXPERIMENTS WITH THE FUNGUS.

Table I gives complete inoculation data for this fungus on *Comandra umbellata*. Successful inoculations were made with æciospores from two hosts, *Pinus ponderosa* and *Pinus pungens*, collected from three widely separated localities in the States of Washington, California, and Pennsylvania. In each instance control plants of the same species were used, and all remained free from infection. Unsuccessful inoculations were made with æciospores from *Pinus contorta* (*Peridermium betheli*) both during 1913 and 1914. In 1914 the failure to infect might have been due to the extreme high temperature of the greenhouse at the time the inoculation experiments were performed. However, the failure for two successive seasons to infect *Comandra* with the æciospores from *Pinus contorta* may indicate that the rust on this host is a different species from *Peridermium pyriforme*, since the shape and size of the æciospores (*P. betheli*; Pl. I, fig. 3) from *Pinus contorta* are different from those of the type specimen of this rust (Pl. I, fig. 1). The writers, in the absence of proof from inoculations, assume for the present that these morphological differences may be due to the host and therefore are not of sufficient importance to warrant classifying *Peridermium betheli* as distinct from *P. pyriforme*.

TABLE I.—Results of inoculations with the æciospores of *Cronartium pyriforme*.

Æcial host, serial number, and locality.	Species inoculated.	Date of inoculation.	Results.			Collector.
			Uredinia.	Telia.	Degree of infection.	
<i>Pinus contorta</i> :		1913				
8500, Eldorado Springs, Colo.	<i>Comandra umbellata</i>	June 18	.....	.....	No infection..	Bethel.
8500 ¹ , Eldorado Springs, Colo.	<i>Comptonia asplenifolia</i>	do	.....	.....	do	Do.
8514, Allenspark, Colo.	<i>Comandra umbellata</i>	June 27	.....	.....	do	Do.
Do.	<i>Castilleja linearis</i>	do	.....	.....	do	Do.
<i>Pinus ponderosa</i> :		1914	1914	1914		
12467, Wenatchee, Wash.	<i>Comandra umbellata</i>	May 27	June 5	June 28	Sparse ²	Fisher.
Do.	do	May 30	June 9	July 4	do	Do.
12468, Rocky Gulch, Cal.	do	May 28	June 6	July 5	do	Boyce.
<i>Pinus pungens</i> :						
15444, Greenwood Furnace, Pa.	do	May 29	June 7	June 30	Very abundant.	Hedgecock.
15455, Greenwood Furnace, Pa.	do	May 30	June 10	July 15	do	Do.
Do.	do	do	June 11	do	do	Do.
15462, Greenwood Furnace, Pa.	do	June 1	do	July 1	Sparse	Do.
Do.	do	June 2	June 12	July 4	Abundant ³ ...	Do.
Do.	do	June 13	June 13	July 8	do	Do.
Do.	do	June 3	do	July 5	Sparse	Do.
<i>Pinus contorta</i> :						
15550, Eldora, Colo.	do	July 3	.....	.....	No infection ⁴ ..	Do.
Do.	<i>Ribes longiflorum</i>	do	.....	.....	do	Do.

¹ Type of *Peridermium betheli*.

² Sparse here means less than six sori.

³ Telia immature.

⁴ Inoculation made in very hot weather.

A study of Table II and of figures 1 and 2 of Plate I shows some very interesting facts. For instance, the shape and size of the spores from the type material (Pl. I, fig. 1) and those from *Pinus pungens* (Pl. I, fig. 2) are practically identical, since the range in size for 20 spores of the type is 19 to 25.6 μ by 41.6 to 73.6 μ with an average for 20 spores of 23.4 by 58.6 μ , and for 20 spores from *Pinus pungens* the range is 19 to 25.6 μ by 42 to 73.6 μ with an average for 20 spores of 23.1 by 59.1 μ . This close similarity in size and shape would indicate that the type may have been on *Pinus pungens*, but this does not seem probable if the type really came from Newfield, N. J., as *Pinus pungens* has not been reported from this locality, although Britton (4) reports it as abundant 1 mile east of Sergeantsville, in Hunterdon County. It is possible that sporadic or introduced specimens of *Pinus pungens* may have been growing near Newfield at the time the collection of the type specimen of *Peridermium pyriforme* was made. The alternate stage of the rust, *Cronartium pyriforme*, on *Comandra umbellata* was collected at Newfield, N. J., by Ellis in August, 1879, and issued by him in North American Fungi under the number 1082. This indicates that the type material of *Peridermium pyriforme* came from New Jersey.

TABLE II.—Measurements, shape, etc., of the ascospores of *Cronartium pyriforme*.

Æcial host, serial number, and locality.	Measurement (microns).		Shape.	Acumination.
	Range in size.	Average for 20 spores.		
<i>Pinus pungens</i> : 15462, Greenwood Furnace, Pa.	19 to 25.6 by 42 to 73.6.	23.1 by 59.1..	Obovate or pyriform to subclavate or spatulate.	Often very long (Pl. I, fig. 2).
<i>Pinus</i> sp.: Type, Newfield, N. J. (?)	19 to 25.6 by 41.6 to 73.6.	23.4 by 58.6..	Obovate to pyriform or subclavate.	Often very long (Pl. I, fig. 1).
<i>Pinus ponderosa</i> : 15556, near Darby, Mont..	19 to 25.6 by 38 to 64.	22.4 by 48.6..	Obovate to pyriform or rarely ellipsoid.	Often not very pronounced.
12467, Wenatchee, Wash..	18 to 25.6 by 38 to 64.	21.1 by 51.5..	Obovate to pyriform.	Do.
12468, Rocky Gulch, Cal..	20.8 to 25.6 by 35 to 70.4.	23.9 by 54.5..	do.....	Do.
<i>Pinus ponderosa scopulorum</i> : 12470, Crook National Forest, Ariz.	19 to 27 by 32 to 64.	21.8 by 44.3..	Ellipsoid or obovate to pyriform.	Usually very short.
<i>Pinus contorta</i> : 15550, Eldora, Colo.....	15 to 25.6 by 25 to 45.	18.1 by 40.2..	do.....	Usually very short (Pl. I, fig. 3).
8500, Eldorado Springs, Colo.	15 to 26 by 25 to 48.	20 by 43.....	do.....	Usually very short.

The senior writer, during August, 1914, visited Newfield and several other localities in the same region. He found the same species of pine here that are known to occur in southern New Jersey and that probably were present at the time of the Ellis collection, viz, *Pinus echinata*, *P. rigida*, and *P. virginiana*. None of these were found by him to be diseased with the *Peridermium* of *Cronartium pyriforme*.

Comandra umbellata observed in a number of these localities was also free from the rust.

In 1914 the senior writer found *Pinus pungens*, *P. rigida*, and *P. virginiana* closely associated in a mixed forest near Greenwood Furnace, Pa. In this instance *Pinus pungens* was attacked by *Peridermium pyriforme* so badly that in some places more than 50 per cent of the trees were killed, and although *Comandra umbellata* plants bearing the telial form of the rust were present in abundance, no pines of either of the other species were diseased. This indicates that these two species of trees are immune and that neither can be the host for the type specimen that Ellis found at Newfield. Of the five species of pines known to be the æcial host of this fungus, not one is a strictly three-needle pine. All have either two or two to three needles in the leaf clusters. This makes it seem improbable that *Pinus rigida* was the host of the type material. *Pinus echinata* is a two to three needle pine found in southern New Jersey, and this species may have been the host of Ellis's type.

The cultural work done by the writers with *Peridermium pyriforme* Peck proving it to be the æcial stage of *Cronartium pyriforme* (Peck) Hedge. and Long on species of *Comandra* completes the life history of all the caulicolous species of *Peridermium* as now recognized in the United States. There are four native and one introduced species and each constitutes the æcial stage of a species of *Cronartium*:

- (1) *Peridermium pyriforme*, which is the æcial stage of *Cronartium pyriforme*.
- (2) *Peridermium cerebrum* Peck is the æcial stage of *Cronartium cerebrum* (Peck) Hedge. and Long on species of *Quercus* and *Castanopsis*. This is a well-recognized eastern species and, including its western form, *Peridermium harknessii* Moore, is the only native gall-forming *Peridermium* in the United States. *P. harknessii* on *Pinus radiata* Don is synonymous with *Peridermium cerebrum*, since it is associated with *Cronartium cerebrum* on *Quercus agrifolia* Née on the Monterey Peninsula in California. The other forms of *Peridermium harknessii* may not belong here, and until cultural proof of their identity with *P. cerebrum* is obtained, the forms on *Pinus ponderosa*, *Pinus contorta*, and other western pines remote from species of *Quercus* and *Castanopsis* can only be doubtfully referred here.
- (3) *Peridermium comptoniae* (Arth.) Orton and Adams, a well-known eastern species, usually occurring on the pitch pine (*Pinus rigida* Mill.) in the eastern and north-eastern United States, but also attacking two to three needle species, is the æcial stage of *Cronartium comptoniae* Arth. which attacks *Comptonia peregrina* (L.) Coult. and *Myrica gale* L.
- (4) *Peridermium filamentosum* Peck on *Pinus ponderosa* and *Pinus contorta* is the æcial stage of *Cronartium filamentosum* (Peck) Hedge., which attacks a number of species of *Castilleja* in the western United States over a wide region, ranging from the Rocky Mountains to the Pacific coast. *Peridermium stalactiforme* Arth. and Kern and *Cronartium coleosporioides* (Dietel and Holway) Arth. and Kern are synonymous with this species.
- (5) *Peridermium strobis* Kleb., an introduced species, is the æcial stage of *Cronartium ribicola* Fisch. de Waldh., which attacks many species of *Ribes*. In Europe this *Peridermium* attacks several species of white (5-needle) pine. In the United States it has been found on only one species, *Pinus strobus* L.

For a number of years Prof. E. Bethel has collected from the leaves of *Ribes longiflorum* at Denver, Boulder, and elsewhere in Colorado a species of *Cronartium* which is apparently not identical with the European *Cronartium ribicola*. The senior writer collected abundant specimens of the uredinial and telial forms of this rust both at Boulder and Denver, Colo., in October, 1914. The telia of this *Cronartium* are larger, more abundant, and much more conspicuous than those of the European species. Although the fungus has been epidemic for several years on the Chautauqua grounds near Boulder, two young white pines (*Pinus strobus*) on the grounds not far from the diseased *Ribes* were free from the disease. This species apparently is able to winter over on *Ribes* plants in the uredinial form. It may yet be found that the æcial form is a *Peridermium* on one of our native pines.

DISTRIBUTION OF THE FUNGUS.

DISTRIBUTION OF THE ÆCIAL FORM.¹

The æcial form of the fungus, *Peridermium pyriforme*, is widely distributed in the United States, having been found in 10 States:

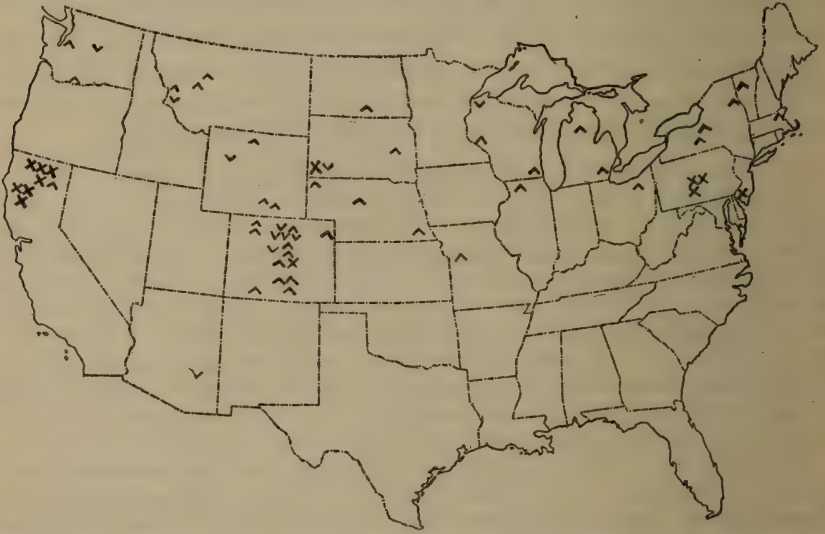


FIG. 1.—Outline sketch map of the United States, showing the known distribution of *Cronartium pyriforme*. Localities where collections of the different forms of the fungus have been made are indicated as follows: v, Æcial form on species of pines; ^, uredinial and telial forms on species of *Comandra*; x, all forms.

Arizona, California, Colorado, Montana, New Jersey, Pennsylvania, South Dakota, Washington, Wisconsin, and Wyoming (fig. 1); and when a more careful search is made for the fungus, in the light of our present knowledge, it will no doubt be found to have a much more general distribution in this country. It has also been found in Alberta and British Columbia.

¹ All specimens cited except those marked with a star (*) have been examined by one of the writers.

DISTRIBUTION IN THE DOMINION OF CANADA.

Alberta.—On *Pinus contorta* (*P. murrayana*): * Devil's Lake, Banff, by Holway (3, p. 127), in 1907.

British Columbia.—On *Pinus ponderosa*: * Vernon, by Brittain, in 1913.

DISTRIBUTION IN THE UNITED STATES.

New Jersey.—On *Pinus* sp.: (Type) Newfield, by Ellis (2040), in 1882 (Herbarium New York State Museum).

Pennsylvania.—On *Pinus pungens*: Charteroak, by Orton and Adams, in 1913 (F. P.¹ 15129); Greenwood Furnace, by Hedgcock, in 1914 (F. P. 15444, 15455, and 15462); Petersburg, Huntingdon County, by Hedgcock, in 1914 (F. P. 15483).

Wisconsin.—On *Pinus divaricata*: * Douglas County, by Davis.

South Dakota.—On *Pinus ponderosa scopulorum*: * Rockerville, by White; Black Hills near Custer, by Hedgcock and Phillips (F. P. 15826) and by Hedgcock (F. P. 15801), in 1914.

Wyoming.—On *Pinus contorta*: Dubois, by C. E. Taylor, in 1914 (F. P. 15797).

Colorado.—On *Pinus contorta* (*P. murrayana*): * Gatos (collector not given), in 1906 (3, p. 126–127); Eldorado Springs (F. P. 8500), type of *Peridermium betheli*, Lake Eldora (F. P. 8511), Allenspark (F. P. 8502 and 8514), Arrow (F. P. 8515 and 8494), by Bethel, in 1913; Eldora (F. P. 15550), by Bethel, in 1914.

On *Pinus ponderosa scopulorum*: Monument, by Hedgcock, in 1912; Allenspark, by Bethel, in 1913 (F. P. 8504, 8505, 8510, and 8451).

Montana.—On *Pinus ponderosa*: Darby, by Weir, in 1914 (F. P. 15556).

Washington.—On *Pinus ponderosa*: Wenatchee, by D. F. Fisher, in 1914 (F. P. 12467).

On *Pinus* sp.: * Seattle, by Bonser (3, p. 127), in 1906.

California.—On *Pinus ponderosa*: Trinity National Forest, by Box, in 1912; Rocky Gulch, Siskiyou County, by Meinecke, in 1913; by Boyce, in 1914 (F. P. 12468); Mills Ranch, Goosenest Mountain, Siskiyou County, by Boyce, in 1914 (F. P. 15678 and 15680); Castella, Shasta County; Weaverville and Brown Creek, Trinity County, by Boyce, in 1914.

Arizona.—On *Pinus ponderosa scopulorum*: Crook National Forest, by Swift, in 1914 (F. P. 12470).

DISTRIBUTION OF THE UREDINIAL AND TELIAL FORMS.

Cronartium pyriforme, representing both the uredinial and telial forms of the fungus, has been collected more frequently and over a greater range of territory than the æcial form. It has been found in

¹ Forest-Pathology Investigations number.

Quebec and Ontario in the Dominion of Canada and in the United States in the following States: California, Colorado, Illinois, Massachusetts, Michigan, Missouri, Montana, Nebraska, New Jersey, New York, North Dakota, Ohio, Pennsylvania, South Dakota, Utah, Washington, Wisconsin, and Wyoming (fig. 1).

DISTRIBUTION IN THE DOMINION OF CANADA.¹

Quebec.—On *Comandra umbellata*.²—Seven Islands, by C. B. Robinson (858, Plants of Quebec).

Ontario.—On *Comandra umbellata*.²—London, by J. Dearness (2443, Sydow Uredineen and 3419, Fungi Columbiani); and Point Abino, by J. J. Davis (Herbarium New York Botanical Garden).

DISTRIBUTION IN THE UNITED STATES.

Vermont.—On *Comandra umbellata*: Between Essex Junction and Burlington, by Hedgcock (F. P. 8539 and 8655); locality not given, by A. J. Grout (Herbarium New York Botanical Garden).

Massachusetts.—On *Comandra umbellata*: Magnolia, by Seymour and Earle (210-a and 210-b, Economic Fungi).

New York.—On *Comandra umbellata*: Syracuse (Ex. Herbarium L. M. Underwood); Ithaca, by H. S. Jackson (1458, Flora North America); Mount Defiance, by Peck (Herbarium New York State Museum).

New Jersey.—On *Comandra umbellata*: Newfield, by Ellis (1082, Ellis and Everhart, North American Fungi).

Pennsylvania.—On *Comandra umbellata*: Charteroak, Huntingdon County, by Orton, Adams, and Kirk (9, p. 25); Petersburg, Huntingdon County, by Hedgcock (F. P. 15637). Greenwood Furnace, Huntingdon County, by Hedgcock (F. P. 15653, 15654, and 15657).

Ohio.—On *Comandra umbellata*: Cleveland, by B. T. Galloway.

Illinois.—On *Comandra umbellata*: Oregon, by M. B. Waite (85, 134, 176, and 366).

Missouri.—On *Comandra pallida*: Emma, by C. H. Demetrio (4310, Rabenhorst-Paczschke, Fungi Europæi et Extra-Europæi).

Michigan.—On *Comandra umbellata*: Ann Arbor, by Holway (504, North American Uredinales); Ann Arbor, by F. L. Scribner; Roscommon, P. Spaulding (F. P. 15681).

Wisconsin.—On *Comandra umbellata*: Racine, by J. J. Davis; The Dells, by Underwood (Herbarium New York Botanical Garden).

Nebraska.—On *Comandra pallida*: Dismal River, by Webber (784, Fungi Nebraskenses); Hat Creek basin, by Webber (776, Fungi Nebraskenses); Lincoln, by R. J. Pool (F. P. 17045).

¹ All specimens here listed are in the mycological collections of the United States Department of Agriculture unless otherwise noted.

² These species probably should be *Comandra richardsiana* Fernald, since the collections were made in the range of *C. richardsiana* and out of the range of *C. umbellata* as now recognized.

Wyoming.—On *Comandra pallida*: Big Horn Mountains, by Williams and Griffiths (298-a, West American Fungi); Bear Lodge Mountains, by Griffiths and Carter (298, West American Fungi); Centennial, by E. T. and E. Bartholomew (3705, Fungi Columbiani); near Medicine Bow River, by A. Nelson (1257, Herbarium University of Wyoming).

South Dakota.—On *Comandra pallida*: Iroquois, by F. A. Williams (1914, Fungi Columbiani); Black Hills, near Custer, by Hedgcock and Phillips (F. P. 15827 and 15828).

North Dakota.—On *Comandra pallida*: Beaver Lake, by J. F. Brenckle (78, Fungi Dakotenses).

Colorado.—On *Comandra pallida*: Boulder, by F. E. and E. S. Clements (542, Cryptogamæ Formationum Coloradensium); south of Yuma, by H. L. Shantz, U. S. Dept. Agr. Plant-Disease Survey; Short Creek, Custer County, by T. D. A. Cockerell (99 and 104, Ellis Collection in Herbarium New York Botanical Garden); Soldier Canyon, by J. H. Cowen (168, Ellis Collection); La Veta, by C. A. Crandall (283, Ellis Collection); Pagosa Peak, by C. F. Baker (22, Plants of Southern Colorado); also by F. S. Earle (120, Herbarium New York Botanical Garden); Sangre de Cristo Mountains near Westcliffe, by Hedgcock (F. P. 8082); Steamboat Springs, by Hedgcock (F. P. 3873 and 3889); Monument, by Hedgcock (F. P. 3792, 3839, 15948, and 15950); Palmer Lake, by Hedgcock and Bethel (F. P. 3794 and 3819); Boulder, by Hedgcock (F. P. 15885); Golden, by Hedgcock (F. P. 15888); Palmer Lake, by Hedgcock (F. P. 15907 and 15948); Monument Nursery, by Hedgcock and Pierce (F. P. 15950).

Utah.—On *Comandra pallida*: Locality not given, by M. E. Jones (Herbarium New York Botanical Garden).

Montana.—On *Comandra pallida*: Helena, by F. D. Kelsey; Sandcoulee, by F. D. Kelsey (2419, Ellis and Everhart, North American Fungi); Sandcoulee (80, Montana Flora) and Helena (61, Parasitic Fungi Montana), by F. W. Anderson; Missoula, by Hedgcock and Kirkwood (F. P. 8021).

Washington.—On *Comandra pallida*: West Klickitat County, by W. W. Suksdorf (176, Flora of Washington).

California.—On *Comandra umbellata*: Shasta Springs, by W. C. Blasdale (6 North American Uredinales), by M. A. Howe (101, Fungi California), Herbarium New York Botanical Gardens; Mills Ranch, Siskiyou County, by Boyce (F. P. 15796); Integral Mine, Shasta County, by Boyce; Rocky Gulch, Siskiyou County, by Meinecke; Weaverville and Brown Creek, Trinity County, by Boyce; Goosenest Mountain, Siskiyou County, by Boyce and Rider.

DISSEMINATION OF THE FUNGUS.

Cronartium pyriforme is disseminated by means of its three spore forms—viz., æciospores, urediniospores, and teliospores—each form playing an important rôle in maintaining the succession of generations between pine trees and Comandra plants. The process of infection with this species of rust does not differ materially from that of the white-pine blister rust (12).

The æcia on the table mountain pine (*Pinus pungens*) in Pennsylvania mature from the middle of May to the latter part of June. Farther north on the jack pine (*Pinus divaricata*) they bear their spores somewhat later in the season. On the lodgepole pine (*Pinus contorta*) and the western yellow pine (*Pinus ponderosa*) from Colorado to Wyoming, the period of maturity is from the middle of June to the middle of July. In each region they develop earlier on slopes of southern exposure and at lower altitudes.

The æciospores are discharged in great abundance for a day or two and with lessened abundance for about a week longer. They infect any Comandra plants with which they come in contact. The leaves are most commonly infected, but occasionally the stems and floral parts are attacked. The infection near diseased pine is usually very abundant, decreasing rapidly as the distance increases. An abundant infection from æciospores has not been noted for more than 200 feet from the æcial center, when it is located on small pines. When large pines are diseased in the upper limbs, the distance that the æciospores are blown is greatly increased, and the zone of infection is therefore extended very much, and on mountain slopes may reach the distance of nearly 1,000 feet. This inoculation of Comandra plants by æciospores may well be designated as a primary infection, and that by urediniospores, described in the following paragraph, as a secondary infection.

In 8 to 10 days from the time of inoculation by æciospores the uredinia appear on the leaves of the infected Comandra plants and urediniospores begin to be produced. These are blown about by winds and inoculate other Comandra plants. This secondary infection greatly extends the area of diseased plants. A second crop of uredinia develops in from 8 to 10 days from these secondary infections. This process continues throughout the growing season. It is possible that as many as six or more generations of uredinia may be thus produced in one season, and the fungus may spread several miles in this manner. It is by this method of infection that the fungus spreads the greatest distance in nature, which explains why the form of fungus on the Comandra plants is more common than on the form of pines.

In about 15 days the telial columns develop from the uredinial sori on the Comandra plants. As each column grows older it gradually elongates, and the development of teliospores progresses outward

along the column with its growth. The period of teliospore formation for each telium is from one to two weeks. The teliospores germinate in situ as fast as they mature, without being detached from the telial columns. As each teliospore germinates it develops a basidium, which when typical bears four sporidia. The sporidia borne on each basidium, however, are usually less than four. The sporidia become detached as soon as mature and are carried away by even the slightest breeze. They readily infect the younger part of pine trees, thus completing the life cycle of the fungus. From observation it appears probable that germinating sporidia usually gain entrance into the tissues of the pines through wounds or in wound callus where young cells are exposed. Inoculations with another species, *Cronartium cerebrum*, on pine trees (*Pinus virginiana*) without wounds have failed, while at the same time, other conditions being similar, they were successful in wounds.

Since each generation of uredinia on Comandra plants is followed within a few days by one of the telia, there is a continual production of sporidia from the time the telia first appear till the end of the growing season. This greatly extends the period of possible infection for pines, a period which must be from two to four months, depending upon the length of the growing season in pines, which varies not only at different altitudes and in different latitudes, but also from season to season.

It is highly probable that the various spore forms of this fungus, especially the æciospores from the pines, may be carried about on the bodies of birds and of the smaller animals. In this manner they could be carried even to greater distances than is possible by wind dissemination.

If young pines in nurseries should become infected, the danger of a much wider dissemination of the fungus than has already taken place in nature is at once possible, with man as the agent. Under conditions such as occur in many localities both in the eastern and the western United States it would be easily possible for the pines in nurseries to become badly infected, owing to the abundance of Comandra plants in the vicinity.

EFFECT OF THE FUNGUS ON ITS HOST PLANTS.

EFFECT OF THE ÆCIAL FORM ON PINES.

The immediate effect of the æcial form, *Peridermium pyrifforme*, varies in different species of pines and on the same species under different conditions. When young lodgepole pines or western yellow pines are attacked, either on the trunk or limbs, there commonly develops a slightly swollen area in the region of the infection. If the infected area encircles the trunk, as it usually does, a spindle-shaped or fusiform swelling may result (Pl. II, fig. 3), which varies

from an inch to more than a foot in length. In case of *Pinus pungens* (Pl. II, figs. 1 and 2), fusiform swellings are not so common as in case of *Pinus contorta* and *Pinus ponderosa*. Swelling is commonly not very evident in very young trees of any of these three species. The bark layers are usually thickened in the portions where the rust mycelium is present. So far as can be ascertained from field observations the æcia may not appear until three or more years after infection takes place.

The development of the peridia at the maturity of the æcia ruptures the bark of the diseased areas, forming numerous openings (Pl. II, fig. 2) which reach to the inner layers of the cambium. As a result the death of the cambium layer may take place, due apparently to excessive evaporation of water through the lesions. The part of the tree attacked usually is either girdled and killed outright or it is partially girdled and a canker is formed. Young pines are very commonly girdled and killed during the same season the æcia are produced. In its effect on pines, *Peridermium pyriforme* must be classed with *P. strobi* and *P. filamentosum* and be ranked as one of the most destructive species of *Peridermium* in North America.

In a region adjacent to Greenwood Furnace, Huntingdon County, Pa., the senior writer, during June, 1914, took notes on the number and condition of pines (*Pinus pungens*) diseased with *Peridermium pyriforme*. Again, in autumn, the condition of the same trees was noted, and it was found that of 50 diseased pines upon which the æcia had been found in June, 29 (58 per cent) were dead from the girdling effect of the fungus.

These had apparently died shortly after the æcia fruited, as dead leaves were still clinging to the branches of the trees. The pines examined were small, varying in height from 4 to 10 feet, and in diameter at the ground from 1 to 4 inches. A similar effect was noted during the autumn of 1914 on a smaller number of young pines (*Pinus ponderosa*) in the Black Hills near Custer, S. Dak.

J. S. Boyce, of the Office of Investigations in Forest Pathology, has reported this fungus on the yellow pine (*Pinus ponderosa*) in Klamath, Shasta, and Trinity National Forests in California.¹ This report states that in the Klamath National Forest—

The parasite produced spindle-shaped swellings at the point of infection on the yellow pine, usually on the main stem but occasionally on the branches. These swellings varied from 2 inches to a foot in length.

The fungus on yellow pine undoubtedly kills that portion of the main stem or branch of the tree above the point of infection. A number of small trees were found to have been killed. Each of these bore one or more spindle-shaped swellings on the stem. A volunteer (shoot) had then appeared while a new infection had occurred just below the point where the volunteer joined the main stem. A repeated killing of this kind causes a strikingly deformed tree.

¹ Boyce, J. S. Notes on *Cronartium pyriforme*. Unpublished report submitted December 7, 1914.

The largest infected tree found was 12 feet high and 3 inches in diameter at breast height, approximately 22 years old, with the infection occurring 5 feet from the ground. In another area here 10 saplings killed by the fungus, with only one living uninfected tree, were found.

One diseased area of *Pinus ponderosa* at Mills Ranch on the north slope of Goosenest Mountain in the Klamath National Forest was described by Boyce, which contained at least a hundred acres. The largest tree diseased by the fungus in this area was 8 inches in diameter at breast height. Spindle-shaped swellings were common, but more especially on the younger, smaller trees. The girdling effect and death of the host tree in the parts above the point of infection were very much in evidence in this area. Small trees apparently were girdled and killed much sooner than older trees. Wounds caused by some gnawing animal, presumably the porcupine, were common on trees in areas where the fungous disease occurred. In one of the diseased portions of the forest a sample plat was established by Boyce and a count of the healthy, infected, dead, and dying trees of *Pinus ponderosa* was made. The result was as follows: Out of 314 trees in the plat, 153 (48.7 per cent) were apparently healthy, 52 (16.5 per cent) were plainly diseased by the fungus, 3 (0.9 per cent) were dying, and 106 (33.7 per cent) were dead from the effects of the fungus. In the words of the report:

Over 50 per cent of the total number of trees of the sample plat had been infected, and nearly two-thirds of the total number infected had already been killed. There is, of course, a possibility that the death of some of these might have resulted from other causes, but only those trees were included which I was certain in my mind had been killed by the fungus.

Boyce's data corroborate those taken by the senior writer both in Pennsylvania and South Dakota.

Reporting concerning an area of diseased *Pinus ponderosa* along Browns Creek in Trinity National Forest, Boyce says:

There were many dead trees, undoubtedly killed by the fungus, with spindle-shaped swellings on the main stems. On living infected trees the æcia were sporulating (June 27, 1914), but not very abundantly, not to be compared with the sporulation found at Rocky Gulch on May 20. One infected sapling was found in which the major portion of the bark had been destroyed either by wood rats or porcupines.

Where the trunk is not girdled, cankers or catfaces are occasionally formed by the death of a portion of the cambium. In such cases the continued presence of the fungus in the live tissues beyond the dead area stimulates their growth, and the fungus may fruit a number of times before the tree is killed. Catfaces on the lodgepole pine (*Pinus contorta*) and on the western yellow pine (*Pinus ponderosa*), however, are more commonly produced by another species of rust, *Peridermium harknessii*.

Peridermium pyriforme, when it infects the trunk of a pine tree, may spread from the trunk to such limbs as spring from a point near

the center of infection or, vice versa, may spread from the point of infection on a limb to that part of the trunk adjacent to the diseased area on the limb. In this it resembles *P. filamentosum* (5) and the fusiform type of *P. cerebrum* (*P. fusiforme*) (7, p. 248). Such instances in the case of both *P. pyriforme* and *P. filamentosum* on *Pinus ponderosa* have been observed by the senior writer in Colorado and Wyoming and noted by Spaulding (11, p. 28, 34) in the case of *Peridermium strobis* on white pines in the northeastern United States.

EFFECT OF THE UREDINIAL AND TELIAL FORMS ON COMANDRA PLANTS.

The effect of the uredinial and telial forms of the fungus, *Cronartium pyriforme*, on Comandra plants can not be separated into two distinct sets of symptoms, since the two forms are produced on the same area of tissue, the one following the other in a few days. Both the uredinia or the telia may occur on either surface of the leaves, as well as on the younger portions of the stems, and occasionally on the floral parts.¹ In badly infected plants there is a decided shortening of both the stems and the leaves in their growth, so much so as to change the entire aspect of the plants. This is usually accompanied by a slight chlorosis of the leaves. Where the infection is slight, the diseased spots on the leaves are usually a lighter green color than the uninfected portions. Late in the growing season the reverse coloration sometimes takes place, and the chlorophyll is retained longest in light-green areas in the leaves where the mycelium of the fungus is found, even after the remainder of the leaf has become yellow from fall coloration.

In badly infected Comandra plants defoliation takes place prematurely; that is, before drought, frost, or cold weather bring it about. No data have been obtained as to the final effect of the rust on Comandra plants. The effect, however, is decidedly stunting, and plants infected badly for several seasons would undoubtedly be killed.

ERADICATION AND CONTROL OF THE FUNGUS.

One of the most serious facts in connection with the prevalence of *Peridermium pyriforme* in some portions of the western United States is the danger of introducing it into localities now free from it through the shipment of trees in the work of artificial reforestation. For this purpose nursery stock is often shipped long distances. The forest nursery if situated in mountain regions is apt to be in a locality where Comandra plants are common. Since these serve as host plants for both the uredinial and telial forms of the fungus, their presence may lead directly to the infection of the young pines in the nursery and indirectly to the infection of localities hitherto free from the disease.

¹ In *Comandra pallida* this is the case. In *Comandra umbellata* the uredinia and telia are found uniformly on the under surface of the leaves.

If it were possible to distinguish all of the diseased trees at the time of planting, it would be an easy matter to discard them and thus prevent the further spread of the disease. Such, however, is not the case, since the disease may not become evident until three or four years after the young trees are infected and until after they are planted in the forest. This being the case, other means for the control of the disease must be adopted. The most feasible plan to prevent further infection in the nursery and the subsequent dissemination of the disease through infected nursery stock appears to be the elimination of all Comandra plants in the vicinity of the nursery.

In order to protect the nursery from infection whenever the disease is present in adjacent forests, all diseased pines that can be found within a radius of at least half a mile from the nursery should be cut down. These can be selected most easily by a person familiar with the fungus, at the time the æcia mature in the pines. As previously stated, this period varies from the middle of May till in August, depending upon both the latitude and the altitude of the locality. This cutting-out process should be repeated each year until no more diseased trees can be found in the proposed neutral zone.

The elimination of all diseased pines will not suffice, however, absolutely to control the disease in the nursery when Comandra plants are in the vicinity, since it is quite certain that the fungus can spread by the urediniospores from one Comandra plant to another for long distances in one season. By this means the disease could be carried from diseased pines outside of the neutral zone or belt of removal to the young pines in the nursery. To protect the nursery against infection from this fungus all Comandra plants within 1,000 feet of the outer boundaries of the nursery should be removed by digging them out.

Comandra plants are herbaceous perennials and spread primarily by means of seeds and secondarily by means of underground runners. The secondary method is the more common. The seeds, being edible, are much liked by birds and rodents, and it is possible that they may be carried by these animals to a considerable distance from the original place of growth, thus starting new plant colonies. The eradication of Comandra plant colonies will be difficult, owing to the numerous underground runners, any of which are liable to be broken off and left in the ground to start new plants. It will no doubt be necessary to dig up the plants repeatedly before they can be completely eradicated. All species of Comandra are parasitic and derive part of their food supply from other plants by a direct attachment of the smaller side roots of Comandra to the roots of the host plants. It is not yet known how many species of plants are thus parasitized, but several widely different species are attacked. Species of Vac-

cinium are commonly parasitized. This subject is now being investigated by the writers.

The recommendations here given are based on observations made in forests by the senior writer and not on actual experiments. An attempt to control this disease as recommended here has been planned and will probably be carried out in 1915. Until it is certain that the neighborhood of a nursery is free from this fungus, shipment of stock to uninfected forests should be avoided.

The spraying of pines with Bordeaux mixture or other fungicides for the prevention of infection by *Cronartium pyrifforme* can not be recommended until it is known that this method is effectual in controlling the disease.

The spraying of Comandra plants with a poisonous substance to kill the foliage and tender shoots at the time they might be infected from the æcial form of the fungus on pines should prevent the immediate spread of the disease to the pines in adjacent nurseries. This spraying should be done as soon as the leaves of the Comandra plants are fully developed and before the plants bloom. This would probably be from the latter part of May to the middle of July, depending on the altitude and the latitude of the locality. Should the Comandra plants send forth new growth later in the season it might be necessary to spray a second time. Spraying should be repeated each year as long as any Comandra plants remain alive. Where young pines are present, this method could not be used without killing them, and the uprooting of the Comandra plants is recommended for such areas.

Mr. H. R. Cox, Agriculturist of the Office of Farm Management, Bureau of Plant Industry, has prepared a circular letter giving directions for the use of plant poisons in killing vegetation. This circular follows, more complete directions being obtainable from the office mentioned upon request:

For several years this office has been making tests of various chemical plant poisons for killing all vegetation in such situations as driveways, pathways, tennis courts, railroad rights of way, and similar places. It appears that of the substances there are three that are better than any of the rest, namely, arsenite of soda, common salt, and some form of petroleum. The best one of these for each case will depend upon conditions. It seems to be more economical usually to make a number of comparatively light applications for the purpose primarily of killing the foliage rather than one heavy one to affect the roots as well as the tops.

In the case of most kinds of vegetation excepting the grasses, and especially for vegetation of a broad-leaved character, arsenite of soda is highly effective. The commercial grade may be obtained at about 25 cents per pound from some of the wholesale chemists. If large areas are to be treated, it can be made at home more cheaply by boiling 1 pound of white arsenic and 2 pounds of sal soda in a gallon of water until a stock solution is formed. From 10 to 20 pounds of the commercial arsenite of soda or from 7 to 14 pounds of the white arsenic in the home-mixed formula, either one diluted to make from 50 to 100 gallons of solution, is sufficient to kill most of the foliage on 1 acre.

Common salt may be applied dry, provided it is fine grained and is scattered very uniformly. Salt may be applied more uniformly, however, if it is made into a saturated solution (1 pound to $1\frac{1}{2}$ quarts of water). The latter is usually the most satisfactory form. It should be used at the rate of from 3 to 5 tons per acre, depending upon the character and rankness of the vegetation.

Of the petroleum products, fuel oil is about the most satisfactory, although this is sometimes difficult to obtain, and then only in barrel or tank-car lots. Near the oil fields, crude oil as it comes from the well can be obtained cheaply and is quite satisfactory. The petroleum products should be applied at the rate of from 300 to 400 gallons per acre. If small areas are to be treated, so that the matter of expense is of little consideration, kerosene may be used. The petroleum products seem to be the most effective of all when applied to narrow-leaved vegetation, such as grass; salt seems to be the next in effectiveness on such plats, and arsenic third.

A spraying outfit is best for applying liquid material, excepting the salt brine, with which a sprinkling can or sprinkler will do faster work. The petroleum products are very hard on the rubber parts of spraying outfits, but it is necessary to use a sprayer in that connection on account of economy of application; with very small areas where economy is not to be considered the oils can be applied through a sprinkling can.

In the forest under our present conditions and market values it is not best to advise methods of elimination so expensive as have been given for the protection of nurseries. In badly infected areas of young forest trees, all diseased trees should be cut out whenever possible. This often can be done by the forest officer without very great expense, owing to the small size of the trees. In lumbering, trees diseased with catfaces or cankers should not be left for seed trees, as their vitality has been lowered and they will not produce as good a crop of seed as more healthy trees, and it is also highly probable that the viability of the seed produced by such trees is lower than that produced by more healthy trees. Again, trees with such cankers are often capable of producing æciospores around the border of the cankers and if allowed to remain for seed trees would become centers of infection for the younger generations of trees in the new forest.

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WM. A. TAYLOR, Chief



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PROFESSIONAL PAPER ·

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LARCH MISTLETOE: SOME ECONOMIC CONSIDERATIONS OF ITS INJURIOUS EFFECTS.¹

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INTRODUCTION.

During the past four years, in connection with other pathological problems in the forest, the writer has made an extensive survey of the damage to forest growth by some of the mistletoes of coniferous trees. These parasites are very widely distributed in the forest regions of the Northwest, and occur in such abundance in many localities as to assume a very serious aspect in relation to many forest problems. The extent and nature of the injury done vary greatly with the forest type, the topography, and, in some respects, with the climate. This is well shown in the regions in which investigations are now being conducted. In the dense part of many forest regions, as in the vicinity of the great lakes of Idaho, mistletoe does but little damage. However, in the more open stands bordering on the lakes or along the edge of the valleys of the Priest and Pend Oreille Rivers mistletoe occurs so abundantly on the various conifers as to interfere seriously with the development of some of the more valuable timber trees. About the shores of Lake Coeur d'Alene,

¹The writer wishes to express his thanks to Mr. J. F. Pernot, without whose assistance the analysis of the trees would have been difficult, and to Mr. E. E. Hubert for assistance in the tabulations.

along the Spokane River Valley, and extending to the south into the Blue Mountains of Washington and Oregon the mistletoes are very abundant, especially on lodgepole pine (*Pinus contorta*), yellow pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), and Douglas fir (*Pseudotsuga taxifolia*). In many localities the trees rapidly yield to the suppressing effects of these parasites, causing an open, ragged growth of the crowns, with the production of many brooms. The prevalence of a particular species of mistletoe varies greatly in the same general region. To illustrate: Along the hills fronting on the Pend Oreille River, Idaho, the lodgepole and yellow pine stands are heavily infected. Passing up the Priest River Valley, another mistletoe species appears, working considerable injury to the larch, whereas the same tree, wherever it occurs along the Pend Oreille River, is seldom infected. The yellow pine farther up in the Priest River Valley is not seriously attacked. In the Granite Creek drainage area and beyond the mountains to Sullivan Lake, in the Metaline Falls region of Washington, the larch is again very seriously infected, whereas this mistletoe seldom occurs on the divide between these points. The western hemlock (*Tsuga heterophylla*) in the forests of northern Idaho is practically free from mistletoe, as far as the observations have been carried. In a few of the more open valleys several collections of mistletoe have been made from this tree. At many points in Washington and British Columbia where the writer has had an opportunity to collect, the mistletoe on the hemlock seems more abundant. Numerous collections of mistletoes are at hand from many of the forests of southern Montana, and likewise from the northern part of that State and from central Idaho. A trip through Oregon, Washington, and British Columbia during 1913 yielded much information on the occurrence of mistletoes in those localities, so that it will soon be possible, with the additional data now (1915) being collected, to give a fairly detailed statement of the range of these parasites in the principal forest regions of the Northwest.

In order to obtain reliable figures on the damage to forest growth by these plants, special studies of a directly practical nature are now being conducted in several of the most important forests of the regions indicated. It is believed that the results from these studies will be applicable to all the forest areas of the Northwest where trees of the same species are found infected by the same mistletoe. At the same time, work of an experimental nature, both in the field and in the laboratory, is adding to our knowledge of these parasites. This work is being continued, as having a practical bearing on the mistletoe problem, and will be reported upon as time and occasion permit.

THE LARCH MISTLETOE.

This bulletin deals in the main with the immediate practical results of an investigation of the injurious effects of the larch mistletoe on its host in the Blue Mountain region of Oregon and serves to introduce one of a series of studies on the mistletoes of coniferous trees in general. The larch mistletoe (fig. 1), originally named *Razoumofskya douglasii laricis* by Piper¹ and given as a subspecies of the Douglas-fir mistletoe, has recently been raised by the same writer² to the rank of a full species under the following name and description:

Razoumofskya laricis Piper. Pistillate plants olivaceous, clustered, 5-8 cm. long, branched; joints 1.5-2 mm. thick, sharply 4 angled; staminate swollen, yellow, the flowers in short spikes; lobes ovate, acute; fruit oblong, acutish, bluish, 4 mm. long. Common on *Larix occidentalis*.

The investigation was begun in the Whitman National Forest, Oreg. For some time the general and gradual deterioration of the western larch had been reported as occurring throughout the entire Blue Mountain region. The writer was not aware of the great prevalence of the larch mistletoe in this region until his visit there during the early spring of 1913. From a preliminary survey it soon developed that the primary cause of the deterioration of the larch resulted from the suppressing effects of mistletoe. A probable secondary factor on some of the more exposed sites seemed to be certain climatic influences unfavorable to the host but promoting the better development and spread of the parasite.



FIG. 1.—Staminate plants of *Razoumofskya laricis*. Note the hypertrophy of the branch.

THE FOREST.

The Blue Mountains, in which further studies of the mistletoes are in progress, are well covered with forests. The yellow pine pre-

¹ Piper, C. V. Flora of the State of Washington. U. S. Nat. Mus., Contrib. Nat. Herbarium, v. 11, p. 222. 1906.

² Piper, C. V., and Beattie, R. K. Flora of Southeastern Washington and Adjacent Idaho, p. 80. Lancaster, Pa., 1914.

dominates as the principal tree on all the drier slopes and bench lands. This gives an open character to the forest and is of some significance as regards the growth of mistletoe on the larch wherever this tree is associated with the yellow pine. On the lower elevations the yellow pine often occurs in pure parklike stands, with a ground cover quite characteristic of the typical yellow-pine formation, usually indicated by the absence of any great amount of forest litter and by the uniformity and the small number of species of herbaceous and shrublike plants. On the south slopes and low, dry ridges, where the stand is very open, the yellow pine is quite generally infected with its particular mistletoe, working great injury to the tree. At higher elevations in more moist situations, or even at the same level on protected parts of the typical stand, the yellow pine becomes mixed with larch, Douglas fir, white fir, and lodgepole pine. The yellow pine gives way to greater percentages of larch, Douglas fir, and lodgepole pine on the north and east slopes. The two last-named species support large quantities of their respective mistletoes wherever the conditions are favorable for the development of these parasites. The larch predominates in many north-slope stands, especially in the more open situations. Other forest types in which the larch occurs above 6,500 feet or more are of little importance in this connection, since the species of the types at this elevation are not as seriously infected by mistletoe as those on north slopes of 5,000 feet altitude and less.

The influence of drainage, slope, and the general moisture conditions of the soil on the distribution and vigor of the western larch is well shown in the region studied and is likewise reflected in the prevalence and distribution of its principal parasite. Owing to the general prevailing dryness of the region, the maximum development of the larch is attained in moist draws or in fertile valleys not parallel with the direction of the prevailing winds. In such situations the tree is usually quite free from mistletoe, and uninfected trees often attain a diameter, breast high, of 60 inches or more. A full crown composed of the original branches is retained until late in life, the tree showing few defects except an occasional root-rot or a dead top occasioned by agents other than mistletoe. These situations are more favorable to the development of the host than to the mistletoe occasionally found upon it and must be considered the best sites for growing larch in these regions. On the drier slopes and benches, where the larch is associated more with yellow pine, the influence of the site on the vigor of the mistletoe is at once expressed by its greater abundance and its effects on its host, causing smaller diameters and thinner crowns on the infected trees. Occasionally trees in exactly similar situations for some reason escape the ravages of the mistletoe and attain a size of considerable proportions. The full

crown and degree of vigor shown by these trees late in life prove conclusively that the ragged, suppressed condition of their neighbors is not due wholly to unfavorable climatic or soil conditions, but to the effect of the mistletoe upon them.

On some north slopes where the larch is crowded by lodgepole pine and white fir it becomes suppressed for a time very early in life, as indicated by the zone of suppression in the older trees. Those trees finally escaping by their more rapid growth from the influence of their neighbors usually become infected by mistletoe when the crown spreads out to the light and air above. The opportunities for the mistletoe to attack suppressed trees with crowns overtopped by other species not subject to its ravages are not as great as when the trees are standing more in the open. This is due in part to the other species protecting the larch from seed falling on it, and in part to the fact that permanent tissue incapable of being penetrated by the primary sinker is more rapidly developed in the case of suppressed individuals. New growth is of short duration and fewer vulnerable points of easy infection exist. If the infection of the suppressed trees does occur and the infection succeeds for a time, the mistletoe plant may itself become suppressed, partly from a poor nutrient relationship with its host and partly through lack of light, and eventually may die without producing new infections higher up. The signs of old infections are frequently noted in the area of the zone of suppression in trees that have afterwards escaped from the crowding of their neighbors. If such trees again become infected later in life, they may attain a fair merchantable size before the influence of the parasite is made manifest.

PHYSICAL AND CLIMATIC FEATURES OF THE FOREST REGION.

The later geological history of the Blue Mountains, in which the Whitman National Forest is located, is one of a great basaltic uplift surrounding but not submerging the older granitic formations. The several high and low laterally arranged ridges are composed in the main of granitic rocks, forming a type of soil upon which the yellow pine usually becomes the climax species. Other soil characters induced by local variations of climate, slope, and type of ground cover influence the distribution of the forest trees of this region to a marked degree, and indirectly that of the mistletoe.

Summarizing the chief climatic characteristics of the region, compiled from the reports of the United States Weather Bureau, they are (1) scanty rainfall, (2) wide range of temperatures, (3) low absolute humidity, (4) rapid evaporation, and (5) an abundance of sunshine. The influence of such climatic conditions may be considered in general as unfavorable in a few localities to the best

development of the larch, but decidedly favorable to the mistletoe found upon it. This is at once evident to those familiar with the environmental requirements of host and parasite. The region affords a most instructive study of the advance and predominance of a forest-tree parasite on its host, showing this advance to be in as near an exact proportion as the conditions for its optimum development become more favorable.

The problem of the mistletoes in their ecological relationships, regardless of the fact that they are parasitic, is similar to that of all chlorophyllaceous plants; hence, they respond to light, gravity, and

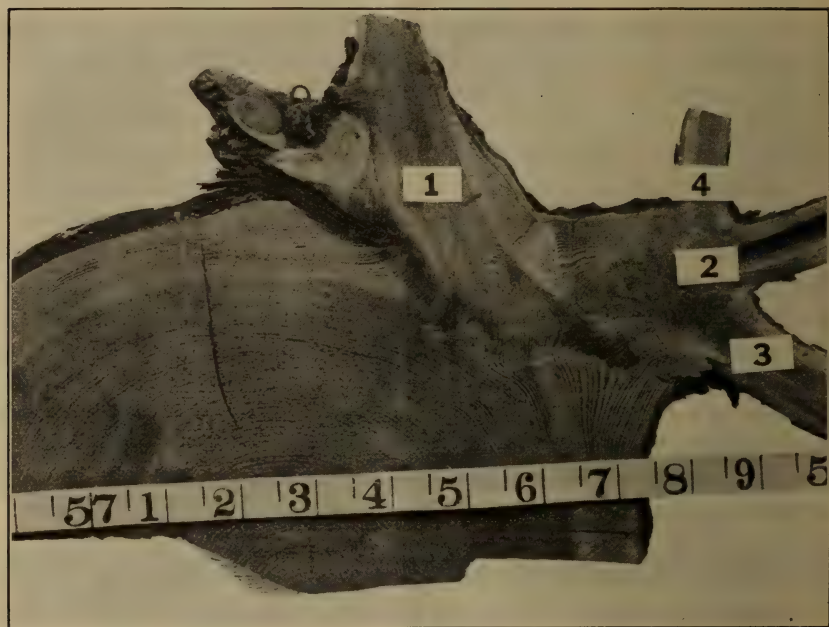


FIG. 2.—Cross section of a part of a trunk of a larch tree, showing the regeneration of branches from the same whorl to the fourth generation. (Tape in feet graduated in tenths.)

chemical influences, and in a far less degree to the influences of temperature and moisture. How, then, do the ecological requirements of the larch mistletoe hold with the climate of the region described, over which the parasite is widely distributed? The great variation in temperature, occasionally abnormally high, and the late, early, and winterkilling frosts of some sections, although seriously injuring the host, produce but little effect on the parasite. The uniform dryness of the air at all seasons of the year throughout the region does not greatly influence the mistletoe plant, which is essentially xerophytic. On the other hand, the large percentage of sunshiny days and the absence of clinging fogs are directly favorable to the parasite, as it is

positively phototropic. The possible influence of the low absolute humidity and rapid evaporation on the entrance of host, reproduction, etc., is counteracted by the parasite by means of special structures enabling it to withstand long periods of drought.

Probably no factor of the region so greatly aids the destructive effects of the mistletoe on the larch as the high, strong winds so prevalent in these mountains. The velocity of the winds is sometimes very great. During 1913 hundreds of reserved yellow pines on the sales area of the Whitman National Forest were uprooted. The wind in this case was materially aided by the insecure rooting of the trees on the surface of a hard stratum of rocks and gravel, together with a certain amount of decay in the brace roots. This is a condition often found in cases of this kind.

Strong winds probably do greater injury to the larch than to any other conifer. An examination of the branching or crown of a mature or middle-aged healthy larch will show that in most cases, especially in windy regions, the tree has been able to reach the standard size only through the production of several generations of branches replacing those broken off by the wind and by other causes (fig. 2). The loss of branches through crowding or natural pruning is not here considered. Trees standing under open conditions from the beginning will show this interesting phenomenon of regeneration. Increasing age, within a certain limit, on the part of the main trunk does not interfere with the anatomical and physiological connections of old branches. Consequently, branches forming at any age sufficiently high on the trunk to escape the influence of suppression should and would remain intact, barring all deteriorating influences, during the natural life of the tree.

Trees with wood exhibiting a natural brittleness, which is always very pronounced at the bases of branches, suffer greatly from breakage by the wind. The western larch is especially subject to this form of injury. The brittleness of its branches at their point of attachment with the main trunk is so pronounced that it is not un-



FIG. 3.—A larch tree of greatly reduced vigor caused by the formation of great witches' brooms and the accumulation of dead leaves and lichens in them. Note that the tips of the branches, also the witches' brooms in the upper portion of the crown, are dying.

common to find them lopped off by the wind. This is especially true of tall stems that have come up in close canopy and afterwards become more or less isolated. In the case of the larch the ill effects of the wind are greatly augmented by the heavy loads of long, trailing lichens (*Alectoria fremontii* Tuck. and *Usnea longissima* Ach.) supported by the branches (fig. 3). During rainy periods these lichens, through the absorption of large quantities of water, increase the weight of the branch by several pounds and, hanging downward in a saturated condition, offer a greater resistance to the wind. The



FIG. 4.—A larch, showing the original crown entirely removed by brooming. The secondary crown is also broomed. The witches'-brooms support large quantities of "black moss" (*Alectoria fremontii* Tuck.), which grows over and mats the foliar spurs.

amount of damage to the larch in many locations from this cause alone is much greater than is ordinarily supposed. In the study in the Whitman National Forest it developed that the injury to the larch by mistletoe (aside from the gradual effects of suppression by brooming up the branches and reducing the assimilatory surface) was in a large measure due to the pruning by the wind of the many branches which, being heavily loaded with witches'-brooms, caused an increased weight to be exerted at their bases. These brooms are often formed far out on the branch and become densely matted with dead leaves and lichens (fig. 3). This increase in weight often amounts to several pounds more than that of a normal branch of the same age and size (Table II) and is further increased by the absorption of water during rainy weather. In the winter the broom furnishes a collecting place for snow. It is very evident how the resultant of the two forces, viz, the wind in a lateral and the weight of the broom-laden branch in a vertical direction, may bring about the removal of all the main original branches (fig. 4). It is not uncommon to find large heaps of branches heavily loaded with brooms under the infected tree. Up to this point the breakage of normal wood uninfected by mistletoe roots has alone been considered.

The infected wood of the branch, either at its base or other portions, where not too greatly enlarged by the stimulating effects of the parasite, requires a much smaller force to break it at the point of infection than is the case in normal branches of like age and thickness. The penetration and embedding of the vertical root system of the parasite in the wood of the host add nothing to the strength of the infected tissue, but diminish its normal strength when the force, as in the case of the wind, is applied at right angles to the grain of the infected branch. Since numerous infections occur at the bases of branches, the point of greatest stress, much injury to the tree results. The meristematic tissue in the cambium layer at the point



FIG. 5.—Cross section of the trunk of a larch tree, showing a typical basal branch burl. Note that the dead wood is attacked by borers which do not encroach upon the living sapwood.

where the branch breaks usually produces secondary branches (see fig. 2). These in turn may become infected and are lopped off, so that eventually great burls are produced at this point on the trunk (fig. 5), seriously reducing the merchantable material. The dead wood thus exposed is a place of entrance for insects and fungi. Since it requires years for the secondary branches to attain a size and assimilatory surface capable of supporting the present bulk of the trunk, the vigor of the tree is gradually reduced. The younger portion of the crown above, being continually encroached upon by the parasite, is not able to supply the deficiency in food materials, and the tree, merely existing for a time, finally becomes a prey to various

deteriorating agents and eventually dies before reaching its maximum development (fig. 6). The radial dimensions of the last annual ring of trees in the final stages of mistletoe suppression (fig. 7)



FIG. 6.—A larch tree in the last stages of mistletoe suppression. A few of the witches'-brooms contain living branches. The tree was making no perceptible increment and was far below the normal size for the region. It was necessary to clear away from the base of the tree the heap of fallen witches'-brooms before it could be cut.



FIG. 7.—Two larch trees barely living, as evidenced by dissection of the bole. Note the very large witches'-brooms and numerous dead branches.

were often so fine and narrow that they could be counted only with the aid of a compound microscope. In some of the worst cases the tree was able to produce but a single layer of tracheids in a year.

In so far as climate influences the prevalence and destructive effects of the larch mistletoe, that of the Blue Mountain region is most favorable. It might be here added that when a particular tree species has succeeded in establishing itself outside of what may be considered its optimum range and at the

same time is followed up by a most destructive parasite which responds favorably to the habitat, the rapid deterioration of the species must necessarily follow, at least in the more unfavorable sites.

FUNGOUS ENEMIES OF THE LARCH.

The larch on the tract examined was not attacked to any extent by fungi. The fungi collected were not present in sufficient quantity nor were their effects sufficiently evident to be considered the prime factor in the universal deterioration of the tree. The dead wood and bark of the mistletoe burls were usually infested by the larvæ of *Melanophila drummondi* Kirby (figs. 5 and 8) and occasionally were followed by a fungus causing a black stain. Two burls were found infected

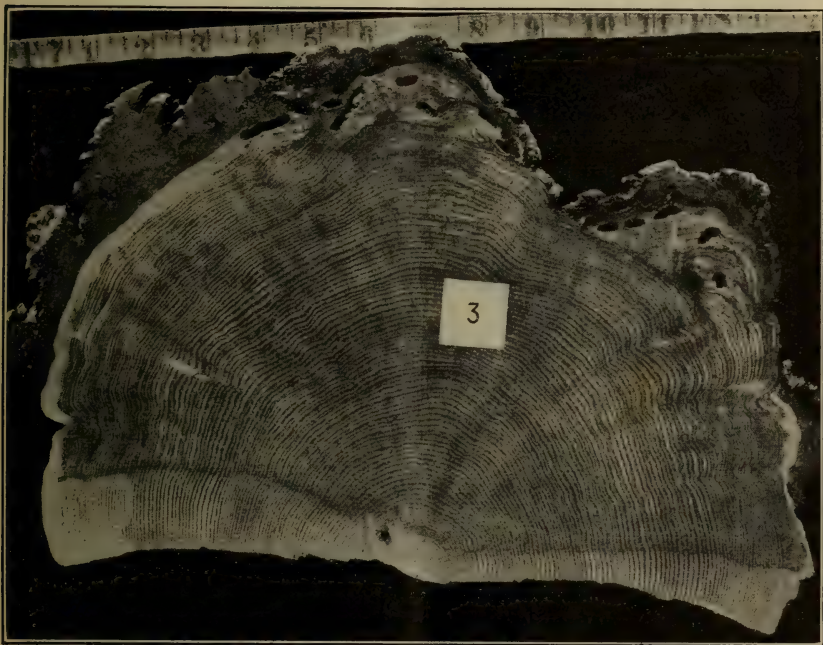


FIG. 8.—Cross section of the trunk of a larch tree, showing characteristic fan-shaped burl tissues resulting from an original infection when the tree was 7 years old. The tree was 145 years old when cut. Note the presence of borers. (Tape in feet graduated in twelfths.)

with *Trametes pini* (Brot.) Fr. (figs. 5 and 9), but here, as in a number of other cases where fungi had entered at the burl, the hardness and pitchy condition of the wood counteracted the advance of the fungus, and it had not spread much beyond the burl tissue. It is safe to state, from long field observations in other regions, that mistletoe burls furnish admirable starting points for fungi; but since the burl in its early stages is very pitchy (fig. 10) and the dead wood becomes pronounced only after the tree is greatly injured by the mistletoe itself, the effect of the fungi is to destroy later the merchantability of the tree, and the mistletoe may not be the original cause of its deterioration.

THE EFFECTS OF MISTLETOE ON ITS HOST.

A preliminary survey by the strip method made at the foot of a north slope and partly on the level resulted in the accumulation of the data given in Table I, showing conclusively that the larch in this region is heavily infected with mistletoe. No attempt was made to ascertain the age of the trees given here, so as to show the degree of suppression. A good idea may be obtained, however, of the nature of the infection, distribution, and quantity of mistletoe present on the trees. In general, the height of the trees here recorded is somewhat less than that of normal or uninfected trees in the same region.

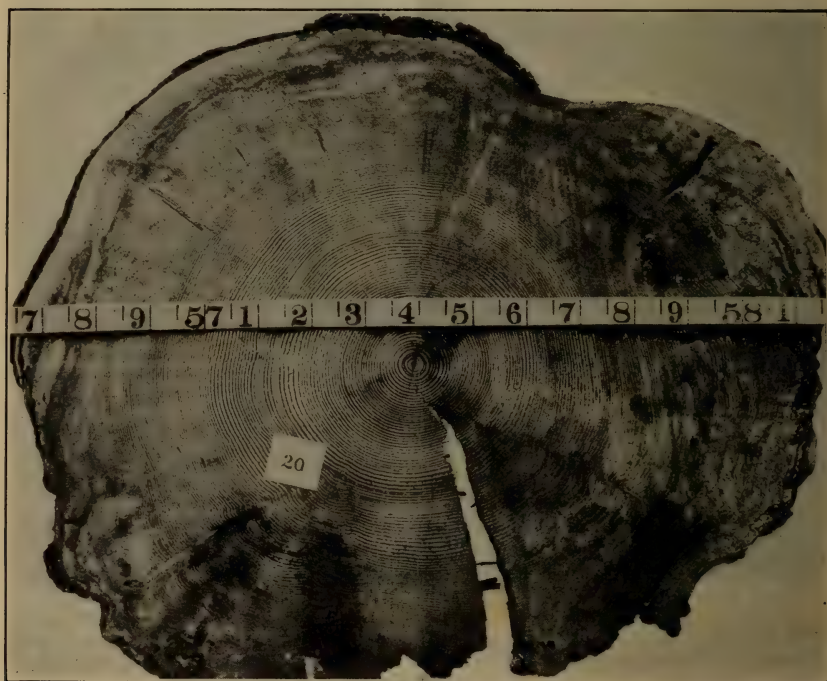


FIG. 9.—Cross section of the trunk of a larch tree, showing a large burl with white cellulose pits caused by *Trametes pini*. Note the small amount of living wood and that the dry wood is attacked by fungi and insects. (Tape in feet graduated in tenths.)

The youngest specimen found infected was less than 5 years old, which means, of course, that such early infection will not allow a very high state of merchantability to be attained, even if the young tree is not killed prematurely. Usually very young growth first becomes infected somewhere on the trunk where the bark is not yet protected by cork (fig. 11). The infection of very young seedlings causes them to assume various abnormal shapes and positions, especially when the mistletoe is confined to one side of the stem. Burl

tissues begin to form usually within a comparatively short time, from one to two years in young plants. If the infection occurs on the stem near the base of a branch, the cortical root system advances into the bast tissues of the branch, initiating a burl or witches'-broom at that point (fig. 1). The extension of the cortical roots upward along the main trunk is sometimes sufficiently rapid to keep within the 4 to 5 year old portion of the stem, although the larch mistletoe seldom



FIG. 10.—Cross section of a trunk of a larch tree with a large burl, showing its structure and a large pitch pocket.

spreads very far from the point of original infection. The parasite, however, usually travels more rapidly along the young shoots which develop in number at the place of first infection. The spread of the parasite outwardly along the branch or upwardly along the leader may be hastened by the dissemination of seeds from the older infections. In this manner the last year's growth is often infected, and even the terminal bud. The branches of the parasite eventually fall away, leaving scars easily discernible on the older parts of the young trees (fig. 1).

TABLE I.—*Extent and nature of mistletoe infection in 36 larch trees in the Whitman National Forest.*

Tree No.	Breast-high diam-eter.	Height of tree.	Number of burls.		Number of witches'-brooms.				General vigor of tree.	General merchant-able condition.
			On trunk.	At base of branches.	At base of branches.	On branches.	Total on tree.	Fallen from tree.		
	<i>Inches.</i>	<i>Feet.</i>								
12.....	7	51	1	4	5	13	18	1	Poor..	.....
16.....	7	68	1	4	6	10	16	1	do...	Poor.
15.....	9	75	0	0	0	0	0	0	Good..	Good.
29.....	10	50	0	0	0	18	18	1	Fair...	Do.
11.....	11	85	0	2	2	12	14	1	do...	Do.
9.....	12	64	0	0	4	15	19	2	do...	Do.
10.....	12	66	0	0	3	16	19	0	do...	Do.
14.....	13	95	0	0	6	12	18	2	do...	Fair.
7.....	14	78	0	0	0	0	0	0	Good..	Good.
23.....	14	122	0	0	0	0	0	0	do...	Do.
5.....	15	98	1	0	4	8	12	2	Fair...	Fair.
13.....	15	84	0	3	4	15	19	3	do...	Do.
17.....	15	83	0	0	0	0	0	0	Good..	Good.
18.....	16	88	1	2	4	20	24	3	Poor...	Poor.
1.....	17	85	0	4	5	15	20	17	do...	Do.
21.....	17	88	2	8	4	20	24	3	do...	Do.
22.....	17	90	0	1	2	11	13	1	do...	Good.
19.....	18	99	1	0	3	8	11	1	Fair...	Do.
25.....	18	103	0	0	0	0	0	0	Good..	Do.
33.....	18	80	1	1	3	5	8	3	Fair...	Do.
2.....	19	99	0	0	0	0	0	0	Good..	Do.
23.....	20	103	1	2	4	18	21	4	Fair...	Fair.
24.....	20	120	0	3	3	20	23	6	do...	Do.
26.....	20	109	3	4	3	21	23	4	do...	Do.
8.....	22	107	1	1	3	10	13	0	do...	Good.
3.....	23	100	2	4	8	8	16	9	Poor...	Fair.
6.....	23	110	3	6	5	16	21	7	do...	Poor.
32.....	23	109	4	2	1	10	11	1	do...	Do.
30.....	24	110	1	2	3	15	18	4	Fair...	Fair.
36.....	25	111	2	3	4	10	14	4	Poor...	Poor.
27.....	28	126	0	0	0	0	0	0	Good..	Good.
28.....	28	110	1	2	1	10	11	2	Fair...	Do.
31.....	28	119	3	1	2	20	22	2	Poor...	Poor.
35.....	29	123	3	4	6	10	16	2	do...	Do.
4.....	29	125	0	14	5	20	25	6	do...	Do.
34.....	30	120	0	3	2	6	8	0	Fair...	Fair.

Owing to the slower growth of the branches in length as compared to the stem, the cortical roots of the mistletoe are enabled to extend into the older part of the 2-year-old internodes. After a time the branch is suppressed and the terminal bud becomes infected, resulting in a terminal broom. The cortical roots likewise penetrate the foliar spurs, causing them to become greatly enlarged, with the result that few leaves are produced (fig. 12). It is remarkable how rapidly in some instances the burl tissues become differentiated. A slight swelling is first noticeable; then the bark begins to lose its fresh appearance, becomes rough around the edges of the infected tissues, and finally separates altogether from the normal bark (fig. 11). The vertical roots of the parasite continue to live for many years, elongating with the same rapidity with which the annual increment of the host is laid down. The hypertrophied tissues resulting from these early infections on the stem spread out in fanlike shapes when viewed in cross section (figs. 8 and 10). Original infections on branches not only cause a local hypertrophy of the immediately

infected area (fig. 13), but large brooms are almost invariably produced.

In mistletoe regions no trees of any age are safe from infection. A great many trees surrounded by other species not attacked by the



FIG. 11.—The main stem of a young larch, showing two separate infections, one at the whorl of branches and the other on the internode. Both infections are of the same age, as indicated by the large primary sinkers, which terminate at the same annual ring. Note the rough bark on the swellings, the beginning of typical trunk burls. The branches of the mistletoe have fallen, but the sinkers are still living and will remain alive for an indefinite period, stimulating the host tissues to a greater development. The central areas of the burl soon die, leaving an open wound.

same mistletoe escape early infection and grow to a fair size, with normal, healthy crowns. Such uninfected trees are always conspicuous among their more heavily infected neighbors. These trees are eventually attacked, but owing to the advantage of a somewhat isolated position, they may not become badly infected, since the seeds must be brought from a distance greater than the natural expelling force of the seed capsule is capable of exerting. Undoubtedly this force is aided by the wind.



FIG. 12.—A larch twig, showing the abnormal size of the foliar spurs when stimulated by the parasite. These spurs are nearly four times the size of the normal spurs on the same branch.

The final result is the infection of the terminal twigs, and in most cases those of the lower branches. The infection gradually spreads upward; the branches either become broomed

and are broken off, followed in many cases by a secondary crown (figs. 3, 4, 6, and 7), too late to supply the deficiency in food materials; or the vigor of the present bulk growth and the vitality of the tree are reduced by a general infection throughout the entire crown. The latter type of mistletoe injury frequently occurs. The tree seems to become infected at many different parts of the crown at once, and while the branches are not broken by the formation of large brooms, the vitality of the host gradually sinks under the drain on its resources of so widespread an infection. When young trees are infected there is such an excessive broom development by the time they have reached pole size that the original crown has practically

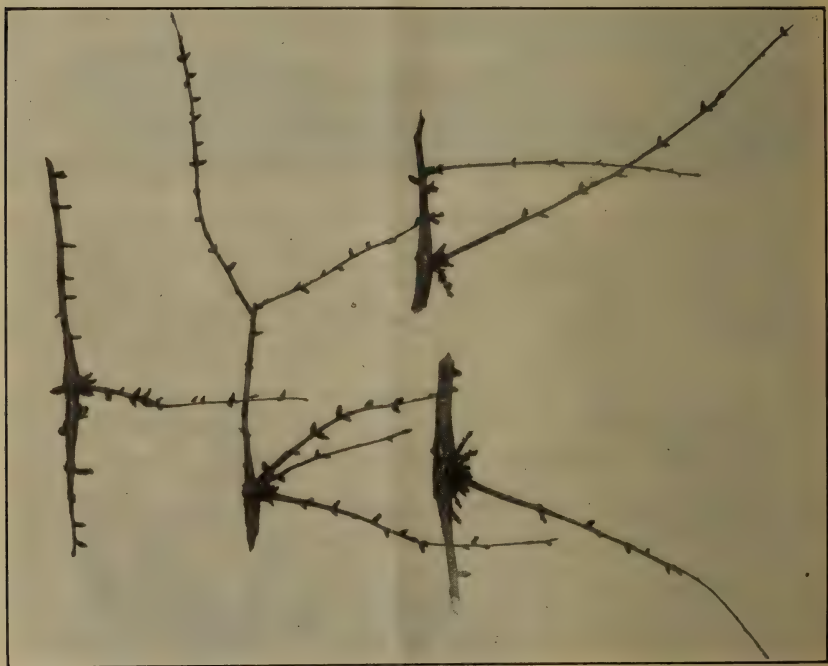


FIG. 13.—A common type of original infection on a larch branch, showing the beginning of branch witches'-brooms.

disappeared. Bushy secondary branches grow out from the stumps of the old ones, and the lopping process may be continued to a third or fourth generation of branches (fig. 2). The width of the secondary crowns becomes less and less, until practically nothing remains but the stubs of the former branches, bearing a few straggling green twigs (figs. 3, 6, and 7). By this means the assimilatory surface of the tree is gradually reduced. During the period between the fall of the primary and the appearance of the secondary branches, the tree is robbed of a great amount of food material necessary to maintain its vigor at its present stage, and it begins to show signs of

developing a "spike top" (figs. 4, 6, and 7). All heavily infected trees by the time they have reached the age of 200 years, if they succeed in living to that age, have developed a "spike top" (Table II).

Occasionally infected trees attain a considerable size, due to the fact that the original infections occurred chiefly at the bases of the branches and did not spread. The attendant broom formation occurring on the branches next to the trunk allows the retention of the branches for a longer time than if brooms were developed farther out on the branch. The merchantability of the tree is greatly reduced, however, by the formation of a series of basal branch burls, causing streaks of pitchy wood to extend along the trunk from one burl to another.

The spread of the parasite in the direction of the prevailing winds was very interestingly shown in a number of cases. One case in particular was noted in which a series of trees of nearly the same age standing in a row extending in the general direction of the more constant winds indicated that the infection had gradually traveled from the first and most seriously infected specimen to those least infected at the other end of the row. These trees had apparently originated under the protection of an old windfall. Since there were no infected trees immediately to the right or left, it is fairly evident that the wind was a factor in seed distribution and also determined the direction of distribution. In order to appreciate thoroughly the significance of the effects of mistletoe on the larch, a study should be made of figures 3, 4, 6, and 7, representing different stages of suppression and various types of infection.

On the drier slopes, from 80 to 90 per cent of the larch of all ages has been found infected. On the more favorable sites, the percentage of infection was very low and therefore did not interfere seriously with the best development of the species. (See trees Nos. 40 and 41, Table II.)

After the preliminary survey, and in order to answer definitely the question whether or not mistletoe is as great an enemy to the host as outward appearance seems to indicate and to obtain, as near as possible, comparable figures on mistletoe injury, 45 infected and uninfected trees were cut and such measurements taken as were thought necessary for the needs of the problem in hand. These data, along with many other observations having a bearing on the subject, have been arranged in Table II, whereby it is possible to follow out the main factors operative in the deterioration or suppression of the trees studied and by means of which fairly conclusive comparisons may be drawn.

TABLE II.—Comparison of 45 larch trees in the Whitman National Forest with respect to mistletoe infection.

[Abbreviations: In columns 14 and 40, increasing degree of infection is shown by the number of cross marks; in columns 26, 31, and 32, B=borers, F=fungi, S=sound, St=stain; in column 36, D=dominant, I=intermediate, S=suppressed.]

Age of tree.	Tree No.	Branch burls.		Branches on burls.		Highest point of infection.	Branch witches'-brooms.	Length of spike top.	Average weight of—		Average diameter of branch.	
		Number.	Average height.	Living.	Originally.				Normal branches.	Branch witches'-brooms.	Supporting witches'-brooms.	Normal, same part of whorl.
1	2	3	4	5	6	7	8	9	10	11	12	13
Yrs.			Feet.			Feet.		Feet.	Pounds.	Pounds.	Inches.	Inches.
30	45											
63	27											
63	42					47.0	7		2.0	3.0	0.5	0.8
74	26											
90	6					Tip.						
94	1											
96	9											
96	43	2	20.0	8	10	57.0	6		3.0	4.5	1.0	1.5
100	7	3	35.3	10	18	80.0	6			4.5	1.3	
105	8	1	23.0	3	4	77.0	5		5.25	3.2	1.3	1.5
106	10	1	23.0	2	2	59.0	24		1.6	3.2	1.0	.75
107	11											
111	4											
119	14											
122	25	8	22.4	23	38	55.5	9			3.8	1.0	
123	5	2	38.0	10	14	82.0	18		2.0	3.0	1.0	.75
123	44											
128	13	3	25.3	15	7	88.5	38		3.2	6.0	1.75	1.50
136	12					108.0	17			8.0	1.0	
143	22											
145	3	5	56.4	15	21	92.0	13		4.5	8.0	1.0	1.75
145	33											
147	19											
180	23	12	41.9	37	72	101.0	10			8.5	1.0	2.10
183	31	6	49.1	6	20	109.0	6		6.0	10.0	1.0	2.0
205	15	12	35.9	14	40	Tip.	(a)		6.0	(a)		
216	16											
222	17	5	37.4	9	21	110.0	11		5.0	8.0	.95	1.8
224	36	5	39.2	10	31	Tip.	1	16				
225	28	4	47.0	3	25	Tip.	(a)		(b)		(b)	
226	35	12	49.0	5	58	Tip.	1		(c)			
227	33	9	71.2	23	51	Tip.	10	10				
229	28	11	45.5	17	53	Tip.	10	12	(d)		(d)	
233	34	5	53.0	3	28	Tip.	(a)		(d)		(d)	
235	18	6	48.3	7	33	Tip.			(e)	(e)		
245	30	5	54.4	4	19				(f)			
245	37	4	43.0	3	21	93.0	2		(g)			
248	32	7	42.0	7	29	Tip.	1			25.0		
249	2	12	37.5	19	85	Tip.		7	(h)			
249	12	10	49.3	5	46			24	(i)			
252	38	6	67.4	10	39	Tip.			(j)			
253	20	3	34.6	2	18	Tip.		42	(k)			
271	24											
566	40											
623	41											

a Branch witches'-brooms fallen to ground.

b Most original branches broken off.

c One original branch.

d Original branches broken off.

e Crown secondary.

f Branches fallen; last stage.

g Crown secondary, infected.

h Branches all fallen.

i Upper crown heavily infected.

j Branches secondary.

k Branches mostly fallen.

TABLE II.—Comparison of 45 larch trees in the Whitman National Forest with respect to mistletoe infection—Continued.

Age of tree.	Tree No.	Degree of infection.	Burls on trunk.													Rings in sapwood (average).	
			Number.	Average height from ground.	Occupied by each burl (per cent.).									Condition.	Width.	Number.	
					Transverse section through center.			Circumference.			Transverse area of living trees.						
					1st	2d	3d	1st	2d	3d	1st	2d	3d				
1	2	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Yrs.				Fect.											In.		
30	45...	xxx	1	4.5													
63	27...	0													0.9	21.3	
63	42...	xx													.53	16.0	
74	26...	0													1.00	21.0	
90	6...	xxx	2	13.5	65	95		65	65		33	100		S	.46	25.0	
94	1...	0													1.34	13.0	
96	9...	0													1.35	27.2	
96	43...	xxx	1	15.0	50			100			10				1.12	23.2	
100	7...	xxx	3	17.0	55	6	15	100	28	20	100	100	100	S	1.29	25.6	
105	8...	xx	1	11.0	20			28			100			S	1.30	24.0	
106	10...	xxx	1	6.0	95			95			100			S	.84	31.2	
107	11...	0													1.32	18.5	
111	4...	xx													1.25	28.2	
119	14...	0													1.62	21.3	
122	25...	xxx	1	Base.	60			35			95			B	1.14	30.6	
123	5...	xx	1	38.0	100			100			70			St	.77	32.6	
123	41...	0													1.50	30.0	
128	13...	xx													.81	25.0	
136	21...	xx													.87	35.0	
143	22...	0													.88	24.1	
145	3...	xxx	3	11.2	60	35	20	60	40	15	40	50	100	B, F	.78	34.7	
145	39...	0													1.34	23.7	
147	19...	0													1.43	28.6	
180	23...	xxx													.71	45.2	
183	31...	xxx	1	16.5	50			50			20			F	.91	38.	
205	15...	xxxx	1	23.0	40			42			40			B, F	.52	50.4	
216	16...	x	1	10.0	70			85			60			B	1.02	34.6	
222	17...	xxx	2	19.5	40	50		50	45		25	90		B	1.00	36.7	
224	36...	xxxx													.38	29.2	
225	29...	xxxx	1	48.0	60			40			10				.46	41.7	
226	35...	xxxx	1		35			40			95			S	.79	43.9	
227	33...	xx													.51	45.3	
229	28...	xxxx	1	27.0	40			50			20			B, St	.43	47.4	
233	34...	xxxx													.53	35.8	
235	18...	xx													.56	44.1	
245	30...	xxxx													.43	42.4	
245	37...	xxx	1	46.0	100			100			40			B, F	1.11	37.1	
248	32...	xxx													.54	43.2	
249	2...	xxx													.38	33.0	
249	12...	xxxx	1												.56	50.4	
252	38...	xxx													.67	44.7	
253	20...	xxxx	1	49.0	80			80			25			B, F	.68	57.0	
271	24...	0													.88	44.0	
566	40...	0															
623	41...	0															

TABLE II.—Comparison of 45 larch trees in the Whitman National Forest with respect to mistletoe infection—Continued.

Age of tree.	Tree No.	Rings comprising present period of suppression.			Condition of heartwood.	Height (feet).		Full volume, b. m.	Dominance.	Diameter, breast high.	Height of stump.	Growth for last 10 years at stump.	Degree of infection.
		Width.	Number.	Condition.		Total.	Merchantable.						
1	2	29	30	31	32	33	34	35	36	37	38	39	40
Yrs.		Inches.						Feet.		In.	Feet.	In.	
30	45	0.25	15	S	S	7	-----	0	S	0.75	-----	-----	xxx
63	27	0	0	S	S	60	-----	40	I	6.65	1.0	0.60	0
63	42	.5	20	S	S	53	-----	25	D	5	1.0	2.80	a xx
74	26	0	0	S	S	52	-----	20	I	6	1.0	.70	0
90	6	.4	30	B	B	51	-----	20	S	6	1.0	1.0	xxx
94	1	0	0	S	S	97	58	340	D	15	1.2	1.20	0
96	9	0	0	S	S	72	32	80	I	9	1.0	1.00	0
96	43	.4	30	S	S	65	30	20	D	6	1.0	.10	xxx
100	7	.2	6	S	S	93	48	165	D	11	1.3	.80	xxx
105	8	.3	4	S	S	95	64	265	D	14	1.2	1.00	xx
106	10	.4	30	S	S	67	0	40	I	7	1.0	.40	xxx
107	11	0	0	S	S	93	64	325	D	16	1.0	2.00	0
111	4	.4	14	S	S	85	48	140	I	11	1.3	.60	xx
119	14	0	0	S	S	122	80	665	D	14	1.5	2.00	0
122	25	0	0	S	S	64.5	16	75	D	9	1.5	.70	xxx
123	5	.3	20	S	S	84	48	170	D	11.5	1.3	.10	xx
123	44	0	0	S	S	95	50	0	D	20	-----	-----	0
128	13	.25	10	S	S	93.5	64	435	D	17	1.5	.50	xx
136	21	.2	0	S	S	114	66	485	D	19.5	1.5	.40	xx
143	22	0	0	S	S	113.5	82	595	D	18	1.5	.80	0
145	3	.2	30	S	S	95	64	240	D	13	1.5	.30	xxx
145	39	0	0	S	S	123	94	1,045	D	22	1.6	1.30	0
147	19	0	0	S	S	102	80	550	D	17	1.5	1.20	0
180	23	2.5	30	S	S	113	82	920	D	21.5	1.5	.10	xxx
183	31	.15	10	S	S	119	82	1,010	D	24	1.5	.30	xxx
205	15	1.2	86	S	S	100	64	430	D	17	1.5	.20	xxxx
216	16	1.2	10	S	S	131	92	720	D	18	1.0	.40	x
222	17	.25	25	S	S	119	80	885	D	21	1.5	.70	xxx
224	36	.15	20	S	S	86	50	160	I	11	1.5	.10	xxxx
225	29	.5	40	S	S	106	82	590	D	19	1.5	.20	xxxx
226	35	.45	35	S	S	121	82	790	D	20	1.5	.20	xxxx
227	33	.4	38	S	S	131	98	1,540	D	26	1.8	.10	xx
229	28	.25	36	S	S	107.5	82	700	D	18	1.0	.10	xxxx
233	34	.15	14	S	S	104.5	65	380	D	16	1.5	-----	xxxx
235	18	1.5	73	S	S	121	80	820	D	20	1.0	.20	xx
245	30	.75	43	S	S	113.5	82	675	D	19	1.3	.20	xxxx
245	37	1.15	6	S	S	97	60	380	I	14	1.5	.60	xxx
248	32	.25	20	S	S	84.5	50	305	S	14	1.5	.10	xxx
249	2	2.5	80	S	S	112	90	905	D	21	1.4	.20	xxx
249	12	1.9	95	S	S	88	48	470	D	18	1.0	.06	xxxx
252	38	.25	20	S	S	120.5	82	780	D	21	1.5	.20	xxx
253	20	.6	50	S	S	112	81	870	D	21	1.4	.20	xxxx
271	24	0	0	S	S	133.5	98	1,905	D	31	1.5	.40	0
566	40	-----	-----	-----	S	160	-----	-----	-----	43	2.0	.40	0
623	41	-----	-----	-----	S	165	-----	-----	-----	51	2.0	.50	0

a The section passed through burl tissues.

The trees were selected from a comparatively small area after the preliminary survey had shown the nature of the deterioration to be universal and similar over large areas of the same type of stand. Although the numerical basis for the figures in the table is very meager, interesting results are shown, which fully justify the arrangement. In the absence of suitable volume-table studies of the normal growth of the same age class for the region, the arrangement of the table is based entirely on the trees felled for study. An increasing degree of infection is indicated by the larger number of cross marks employed (columns 14 and 40). Selecting trees of the same age, the study of the table may proceed as follows: Trees Nos. 42 and 27 are of the same age. The infection of No. 42 is xx; of No. 27, 0. By consulting column 27 the average width of sapwood for tree No. 42 is found to be 0.53 inch, and column 28 shows that the sapwood consists of an average of 16 rings; tree No. 27 has an average width of sapwood of 0.9 inch, with an average of 21.3 rings. Tree No. 42 showed a present period of suppression of 20 rings (column 30), the combined width of which is 0.5 inch (column 29); tree No. 27 has no present suppression and is marked 0 in the table. The condition of the sapwood, sound for both trees (column 31), indicates the absence of secondary causes of deterioration, as does in like manner the column (32) on the condition of the heartwood. Referring to other columns, tree No. 42 is shown to have a total height of 53 feet (column 33), a full volume of 25 feet, board measure (column 35), a breast-high diameter of 5 inches (column 37), and is dominant (column 36); tree No. 27, on the other hand, has a total height of 60 feet, a full volume of 40 feet, board measure, a breast-high diameter of 6.65 inches, and is sufficiently overtopped and crowned by its neighbors to be marked intermediate.

The fact that the infected tree stood fairly in the open, with no deteriorating agents other than mistletoe associated with it, leaves small room for doubt that the tree was suppressed by the parasite upon it. Table II shows that tree No. 42 has seven branch brooms (column 8), with an average weight of 3 pounds per broom (column 11) on and above the average weight of the normal branch, which is 2 pounds (column 10).

The effects of the mistletoe on its host are further shown by the differences in the diameters of branches supporting brooms and those not so encumbered (columns 12 and 13). The analysis of these trees showed that both individuals started equally, but the measurements and study of all cross sections showed plainly a retarded growth during the last few years of life except at the stump, the section passing through burl tissues (column 40). The age of the tree can not be held responsible for the falling off in increment. A comparison of the measurements taken at the various cross sections and at

the stump was found to vary so little that the stump measurements were adopted to show the falling off in growth for the last 10 years. A study of all the cross sections of tree No. 27 showed a normal growth. It also possesses a crown of larger dimensions. The two trees stood within 100 feet of each other. Selecting from Table II that which is of greatest moment, trees Nos. 43 and 9 may be compared as shown in Table III.

TABLE III.—*Condition of larches Nos. 43 and 9, selected from Table II for comparison.*

Item of comparison.	Tree No. 43.	Tree No. 9.
Age.....years.....	96	96
Breast-high diameter.....inches.....	6	9
Infection.....	xxx	0
Average width of sapwood.....inches.....	1.12	1.35
Average number of rings in sapwood.....	23	27
Width of present zone of suppression.....inches.....	0.4	0
Height.....feet.....	30	0
Merchantable length.....do.....	65	72
Full volume, board measure.....do.....	20	32
Growth for last 10 years.....inches.....	20	8)
Relation to neighboring trees.....	0.10	1
	Dominant.	Intermediate.

Tree No. 43, as shown by the data in Table II, had burls on its trunk and at the bases of branches (columns 3 and 15). A trunk burl occupied 100 per cent of its total circumference (column 20) and only 10 per cent of it was living (column 23). The tree had six branch brooms (column 6), with an average weight of 4.5 pounds (column 11), and normal branches of 3 pounds average weight (column 10).

In this manner tree No. 5 may be compared with tree No. 44; No. 10 with No. 11; No. 3 with No. 39; No. 5 with No. 25; No. 33 with No. 35; No. 2 with No. 12; No. 30 with No. 37; No. 33 with Nos. 35, 29, or 36; No. 18 with No. 34, etc.

EFFECT OF MISTLETOE BURLS ON THE MERCHANTABILITY OF LARCH TREES.

The effect of the formation of burls on the trunk and at the bases of branches, aside from injuring the tree from a physiological standpoint by cutting off the transporting tissues, introduces a cull factor of no mean proportion in the present timber capital. In bucking the tree it is possible in most cases to saw out the burls when they are far enough apart not to interfere seriously with the merchantable log length. In badly infected specimens the trunk and branch burls (figs. 5, 8, 9, and 10) are frequently so close together and so evenly distributed along the trunk that little merchantable material can be obtained. Sometimes these burls take up the entire merchantable

part of the tree and are very frequently more than 10 feet in length. Streaks of discolored wood, usually pitchy, and long checks may often extend from burl to burl, producing a very poor grade of lumber. Table IV shows the quantity of culls resulting from the mistletoe burls.

TABLE IV.—*Culled larch lumber resulting from mistletoe burls.*

Age of tree.	Tree No.	Trunk burls.						Basal branch burls.			
		Burl No.	Average diameter.		Length.	Volume, b. m., of culls due to burls.		Maximum diameter. ^a	Number.	Volume, b. m., of culls due to burls.	
			At base.	At top.		Each.	For tree.			Each.	For tree.
Years.			Inches.	Inches.	Feet.	Feet.	Feet.	Inches.		Feet.	Feet.
90	6.....	{ 1	6.6	6.1				7.0			
96	43.....	{ 2	3.5	3			(b)	3.5		(b)	165.0
		{ 1								(b)	20
100	7.....	{ 2	12.3	12	1.5	12		{ 12.3	3	1.4	
		{ 3	11.5	11	1.2	9.3	26.8	{ 11.5			28.2
		{ 1	10.1	10	1	5.5		{ 10.1		1.4	
105	8.....	{ 1	15.1	14.8	3	25	25	{ 15.1	1	2.5	27.5
106	10.....	{ 1	8.1	7	9	14.5	14.5	{ 9	1	1.4	15.9
122	25.....	{ 1	13.5	12.7	3	20	20	{ 13.5	8	20	40
123	5.....	{ 1	8.6	8.3	2	8	8	{ 16	2	5	13
128	13.....	{ 1						{ 10	3	10	10
		{ 5						{ 30	5	30	
145	3 ^c	{ 1	12	11.8	2.3	15		{ 12			
		{ 2	11.6	11.5	2	10		{ 11.6			
		{ 3	11.4	11.3	2	6.5	37.5	{ 11.4			67.5
		{ 4	10.8	10.6	2	6		{ 10.8		30	
180	23.....								12	180	180
183	31.....	{ 1	23.2	23	3	70		{ 23.2	6	175	245
205	15.....	{ 1	13.1	13	3.5	25	(d)	{ 15.5	12	170	195
216	16.....	{ 1	18.5	18	4	67.5		{ 18.5			67.5
222	17.....	{ 1	18.1	17.9	16	190	212	{ 20	5	80	
		{ 2	17.7	17.5	2	22		{ 18		80	292
224	36.....								5	30	30
225	29.....	{ 1	13.1	13	2.5	20		{ 13.5	4	20	40
226	35.....	{ 1	12.8	12.3	4	25		{ 12.8	12	140	165
227	33.....								9	190	190
229	28.....	{ 1	18	17.8	7	110		{ 18	11	150	260
233	34.....								5	60	60
235	18.....								6	80	80
245	30.....								5	70	70
245	37.....								4	60	60
248	32.....	{ 1	10.9		16	70		{ 12	7	75	145
249	2.....								21	190	190
249	12.....								10	110	110
252	38.....								6	95	95
253	20.....	{ 1	18	17.8	16	210	(e)	{ 19	3	120	330

^a Average diameter taken between middle line of burl and either extremity.

^b Tree culled.

^c See figure 8.

^d See figure 10.

^e See figure 9.

METHOD OF CONTROL.

Since mistletoe is propagated and spreads from tree to tree by means of seeds, the method to be employed in eradicating it is similar to that which is now being adopted in many sales areas for reducing the ravages of forest-tree fungi. Results will be obtained in a much shorter time, however, than in the case of fungous enemies. Mistletoe occupies only the aerial part of the host. Fungi attack all parts—roots, stems, and leaves; hence, cutting an infected tree does not

eliminate some of the worst fungous enemies of the forest. Those of the roots escape and others attacking the aerial portion of the tree afterwards in many cases develop quite as vigorously on the dead wood as before. On the other hand, the mistletoe plant dies with the death of the host. Although the seeds of the mistletoe are expelled from the pericarp with considerable force, they are not carried, even though aided by wind, for great distances, as are the spores of fungi. Birds and rodents¹ are factors in the distribution of mistletoe seeds, but the actual service rendered the parasite by such agencies is very small. It is very evident, then, that no trees, young or old, infected with mistletoe should ever be selected for seed trees, because all young growth beneath such trees and in the near vicinity would be in great danger of infection. By a gradual process of elimination on every timber-sale area, governed by a clause in the contract requiring the taking down or girdling by fire of every mistletoe-infected tree, much may be accomplished within a comparatively short time.

CONCLUSIONS.

The principal conclusions which may be drawn from the present study are summarized as follows:

The deterioration of the western larch in the more open and exposed stands of the Whitman National Forest is due to mistletoe. Although yellow pine and Douglas fir are the most valuable species, the larch, when free from mistletoe, attains a size on any site, so far as observed, sufficient to merit its being carried along in the rotation with the other species. From the fact that the larch mistletoe finds its optimum development in the more exposed sites, future silvical operations should aim at confining the larch to moist bottoms and protected valleys.

Since the principal defects of the western larch, excluding pitchy butt and shake, originate from mistletoe, the diameter and age limit of this tree may be greatly extended, provided methods for the eradication of the mistletoe are adopted.

The larch mistletoe attacks trees of all ages, from seedlings to the unsuberized parts of mature trees. If not entirely suppressed or killed, trees attacked in early life seldom produce a good grade of merchantable timber. All trees seriously infected show poor health and reduced diameter or height. Trees becoming infected in middle life may have the quality of the timber reduced by the large knots formed by the basal branch burls.

¹ The common English sparrow has been observed by the writer to feed upon the seeds of the yellow-pine mistletoe in the city park at Coeur d'Alene, Idaho. Mistletoe seeds have been found in the excrement of birds in mistletoe regions. Birds and rodents frequently build their nests in mistletoe brooms and are known by actual investigation to play a minor rôle in the distribution of the seeds of the parasite.

Burls found in early life on the trunk cause suppression by reducing the food-transporting tissues, form open wounds for the entrance of fungi and insects, and cause streaks of pitch to appear in the wood, which often extend from one burl to another. Burls formed at the bases of branches produce similar injuries and may also cause a premature pruning of the branch.

The extra weight of the brooms, together with the accumulated debris, causes the branches to break off readily under the influence of the wind and deprives the tree of its normal food supply.

Mistletoe thrives best on trees of uneven stands. In dense, close, even-aged stands, as in deep valleys, the parasite usually causes less damage.

The type of infection working the greatest injury in the shortest time is the formation of brooms on the branches.

Thinning promotes the development of the parasite in the crown; hence, all infected trees of any size, age, and condition should be marked for cutting.

The mistletoe spreads more rapidly in the crowns of younger trees, owing to the greater number of twigs in close proximity susceptible to infection.

Two types of infection by the mistletoe occur: (1) By the seed falling on the branches, where a broom usually develops if infection occurs, and (2) the gradual advance of the cortical root system of the mistletoe along the branch to younger tissues. The seeds of mistletoe have been known to fall on the healing tissue of wounds on old parts of trees, causing infection.

Suppression by mistletoe causes a more rapid and an earlier formation of heartwood in the younger age classes, thus inviting insects and fungi at earlier periods of growth.

Mistletoe may be controlled by inserting in all timber-sale contracts a clause requiring the cutting on the sales area of all larches infected with mistletoe, whether merchantable or unmerchantable.

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WM. A. TAYLOR, Chief



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PROFESSIONAL PAPER

June 17, 1916

MISTLETOE INJURY TO CONIFERS IN THE NORTHWEST.¹

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INTRODUCTION.

It is not generally known that the injury by the mistletoes to coniferous trees in the northwestern United States is such as to assume in many regions the nature of a serious forest problem. The aim of this bulletin is to point out some of the direct and indirect results of this injury. The species of trees most subject to injury are *Larix occidentalis* (western larch), *Pinus ponderosa* (western yellow pine), *Pinus contorta* (lodgepole pine), and *Pseudotsuga taxifolia* (Douglas fir). Each of these trees is attacked by a particular species of mistletoe of the genus *Razoumofskyia* (*Arceuthobium*). With a few exceptions, these species very rarely occur in nature on any other than their common hosts. In the order of the above-named hosts they are *Razoumofskyia laricis* Piper (Pl. I, fig. 1), *R. campylopoda* (Engelm.) Piper (Pl. II, fig. 2), *R. americana* (Nutt.) Kuntze (Pl. I, fig. 2), and *R. douglasii* (Engelm.) Kuntze (Pl. II, fig. 1).

¹ Thanks are due Mr. E. E. Hubert for assistance in the preparation of the graphs and a number of the other illustrations used in this bulletin.

GENERAL NATURE OF THE MISTLETOE INJURY.

The general nature of the injury to forest growth by these parasites principally consists sooner or later in a localization and gradual reduction of the assimilatory leaf surface of the host. As will be shown, this is caused by various burl and broom formations on the trunks and branches. The reduction of the leaf surface causes a falling off of the annual increment. During the progress of a study on the larch mistletoe in the Whitman National Forest, Oreg., in the summer of 1913, many data on the retardation of growth of its host by this parasite were assembled. More recently, in the lodgepole and yellow pine belt of eastern Washington and northern Idaho, the study was continued on these species, and at frequent intervals on the larch and Douglas fir in the Missoula region of Montana. The method of investigation was as follows: Borings from heavily infected (burled and broomed) and uninfected trees were taken with a Mattison increment borer at $4\frac{1}{2}$ feet from the ground, at which point the trees were calipered. With practice the eccentricity of growth due to slope, unequal crown development, injuries, etc., may be very skillfully judged, so that it is possible to strike the pith of trees within the range of the borer with a fair degree of accuracy. In order to determine as nearly as possible the average radius, in the more doubtful cases three borings were taken. On steep slopes the eccentricity of trees may be more accurately judged than on flat land, through the knowledge that more rapid growth takes place on the downhill side of the tree. Height was computed with the Klaussner height measurer. Trees of the same species were selected as near as possible from the same type of stand and of the same general age class and the same soil conditions. Only dominant trees free from serious wounds and other possible causes of deterioration were recorded. Finding that the effects of the mistletoe on the increment of the host could be read from the last 40 years' growth of the age classes and conditions of infection selected, Table I was prepared.

TABLE I.—*The retardation of growth of forest trees caused by mistletoe, for 40 years, 1874 to 1913, inclusive.*

Host and condition.	Basis (number of trees).	Average.			
		Age class.	Height.	Diameter breast high.	Total annual growth.
		<i>Years.</i>	<i>Feet.</i>	<i>Inches.</i>	<i>Inches.</i>
Pinus contorta:					
Infected.....	50	65	35.2	6.3	0.93
Uninfected.....	50	60	48.5	7.8	2.93
Pinus ponderosa:					
Infected.....	50	100	49.5	18.2	1.54
Uninfected.....	50	100	77.2	22.2	5.33
Larix occidentalis:					
Infected.....	80	144	63.0	11.5	1.28
Uninfected.....	80	144	115.0	19.5	2.154
Pseudotsuga taxifolia:					
Infected.....	40	97	62.0	17.3	2.175
Uninfected.....	40	97	73.0	22.2	3.28

The results in Table I, although based on a relatively small number of trees, prove quite conclusively the effects of mistletoe on the growth of its host. They are graphically shown by the accompanying series of illustrations (figs. 1 to 4).

A glance at these graphs shows that although there is considerable fluctuation in growth, the line of the uninfected rarely falls below that of the infected trees.

These results are not at all surprising when the nature of mistletoe injury is thoroughly appreciated. In a heavily infected region, where all species and ages are more or less involved, dead, dying, or

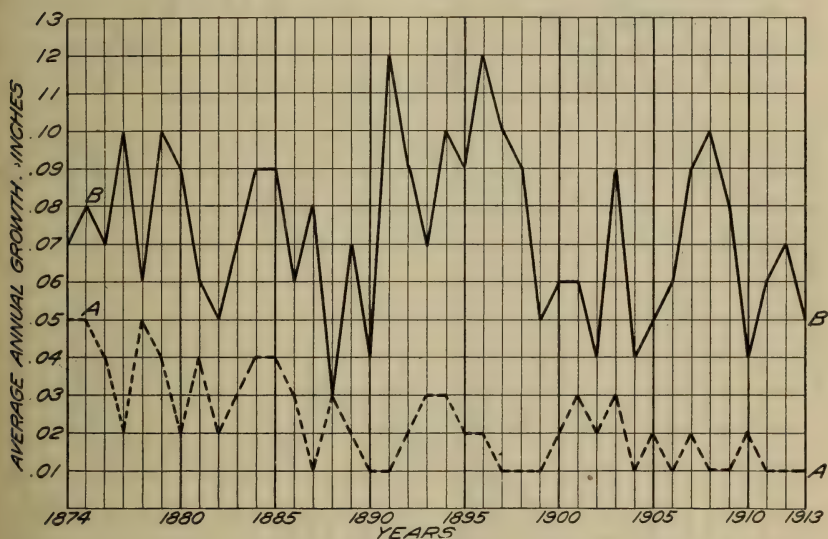


FIG. 1.—Graphs showing the average annual growth (in inches) for 40 years (1874 to 1913, inclusive) of 50 trees of lodgepole pine heavily infected with mistletoe, compared with 50 uninfected trees of the same species for the same period. A, Heavily infected trees: Average-age class, 65 years; average height, 35.2 feet; average diameter, breast high, 6.3 inches. B, Uninfected trees: Average-age class, 60 years; average height, 48.5 feet; average diameter, breast high, 7.8 inches.

weakened mistletoe trees, hastened in their decline by the inroads of fungi and insects, are a common sight. If these trees are carefully examined with respect to the average possible growth for the region, it will be found, as Table I shows, that most of them have died or have become irrevocably weakened or suppressed at a time when rapid or a normal growth should be taking place. This has been found to be true in all regions visited in the Northwest where excessive mistletoe infection is common. Infected trees of immature years, pole size and younger, may linger along indefinitely if secondary agents do not appear and may reach an advanced age, but may not attain a merchantable size. Heavily infected and, as a result of this

infection, badly stunted yellow pine, larch, Douglas fir, and lodgepole pine growing in the open and on otherwise good sites often measure less than 6 inches at the stump, but show ages ranging from 100 to 200 years or more. Young seedlings, if not killed outright within a comparatively short time after infection, usually show a

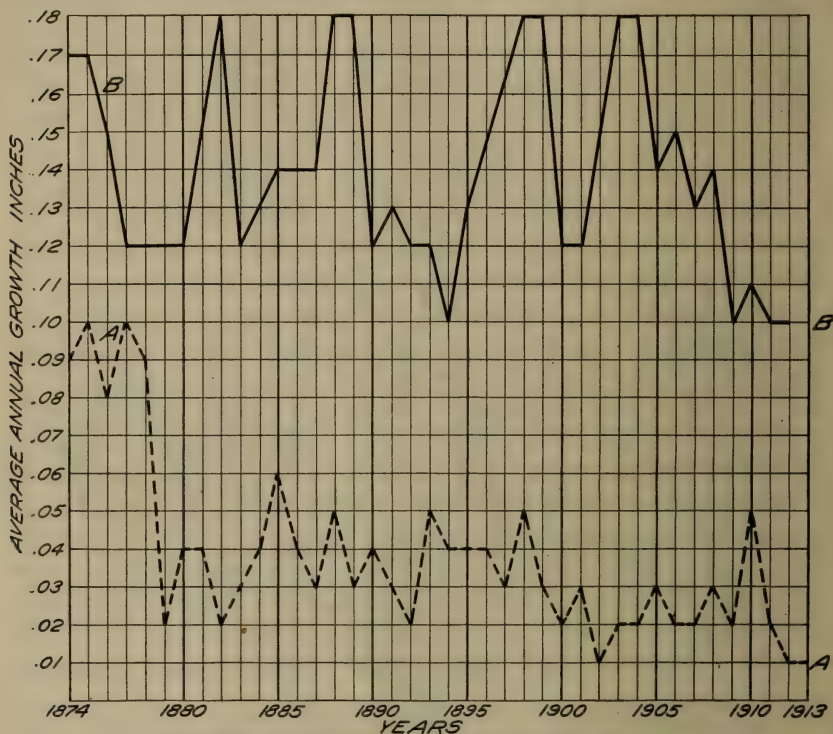


FIG. 2.—Graphs showing the average annual growth (in inches) for 40 years (1874 to 1913, inclusive) of 50 trees of yellow pine heavily infected with mistletoe, compared with 50 uninfected trees of the same species for the same period. A, heavily infected trees: Average-age class, 100 years; average height, 49.5 feet; average diameter, breast high, 18.2 inches. B, Uninfected trees: Average-age class, 100 years; average height, 77.2 feet; average diameter, breast high, 22 inches.

marked falling off of the foliar surface of the parts uninfected and finally succumb to the attack (fig. 5). Very frequently young infected seedlings develop into ball-like brooms.

Table II shows the youngest age class of five hosts at which mistletoe infection has been found to occur and the locality where the observations were made.

TABLE II.—The youngest age class of mistletoe infection on five different hosts.

Host.	Youngest age at which infection is known to occur.	Locality where observations were made.
	Years.	
<i>Pseudotsuga taxifolia</i>	4	Clark Fork Valley, Mont. ¹
Do.....	7	Blue Mountains, Oreg.
<i>Larix occidentalis</i>	5	Priest River Valley, Idaho.
Do.....	4	Blue Mountains, Oreg.
Do.....	3	Missoula, Mont.
Do.....	7	Sullivan Lake, Wash.
<i>Pinus contorta</i>	5	Spokane River, Wash.
Do.....	3	Blue Mountains, Oreg.
Do.....	6	Coeur d'Alene, Idaho.
<i>Pinus ponderosa</i>	5	Spokane River, Wash.
Do.....	3	Blue Mountains, Oreg.
Do.....	4	Coeur d'Alene, Idaho.
<i>Tsuga heterophylla</i>	8	Clearwater River, Idaho.

¹ Valleys of the so-called Bitterroot and Missoula Rivers.

There is no reason why a seedling should not become infected during its first year if seeds should happen to be favorably located upon it. Seeds falling at the base of terminal buds of yellow-pine branches have been known to effect an entrance in the succeeding



FIG. 3.—Graphs showing the average annual growth (in inches) for 40 years (1874 to 1913, inclusive) of 80 trees of western larch heavily infected with mistletoe, compared with 80 uninfected trees of the same species for the same period. A, Heavily infected trees: Average-age class, 144 years; average height, 63 feet; average diameter, breast high, 11.5 inches. B, Uninfected trees: Average-age class, 144 years; average height, 115 feet; average diameter, breast high, 19.5 inches.

season's growth within the year. All infections of firs and spruces have been found on trees ranging from 50 to 150 years. They occurred principally on the branches, resulting in large brooms, so that nothing could be determined as to the probable age of the hosts when infection took place.

No evidence is at hand to show that the primary sinker of these parasites can penetrate other than the more tender epidermis of young parts of the host. Germinating mistletoe seeds located on the smooth bark of the Douglas fir or on the irregularities of older stems of yellow pine or larch have never been observed, even after a protracted contact of the disk of the hypocotyl with the surface of the branch, to penetrate the bark. Removing the exhausted hypocotyl and carefully examining the point where the disk was attached, a barely perceptible pit or indentation is sometimes visible,

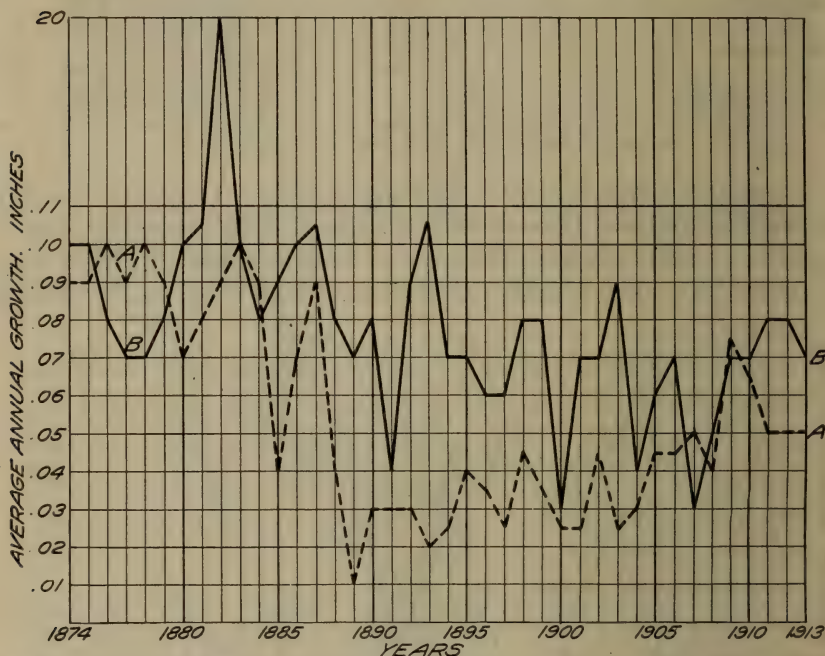


FIG. 4.—Graphs showing the average annual growth (in inches) for 40 years (1874 to 1913, inclusive) of 40 trees of Douglas fir heavily infected with mistletoe, compared with 40 uninfected trees of the same species for the same period. A, Heavily infected trees: Average-age class, 97 years; average height, 62 feet; average diameter, breast high, 17.3 inches. B, Uninfected trees: Average-age class, 97 years; average height, 73 feet; average diameter, breast high, 22.2 inches.

possibly indicating the presence of a solvent, which, however, is ineffective upon more mature bark. There is as yet no proof to support the theory of the presence of a digestive substance which enables the sinker to penetrate the bark more readily. If this were true, infection could possibly occur on older tissues, provided they were not too thick and the food supply in the seed did not become exhausted. As it is, mechanical force, supported by the nonmovable position of the seed, and irregularities of the stems, such as leaf scales, exits of leaf traces, and leaf sheaths, particularly at

the nodes and the basal scales of the terminal buds, are the chief factors in the penetration of the primary root.

The occurrence of mistletoe plants on the thick-barked branches of old trees or on the main trunk are the result of earlier infection, when the bark was thinner. What appears to be a recent infection on the older parts of trees is often merely a retarded or suppressed condition of an earlier infection which has expended most of its energy in the production of a sub-cortical stroma and later breaks through the bark. Periods of suppression and dominance are frequently noticeable in all mistletoes, a condition noted to be in several instances directly referable to the state of vigor of the host. An excessive flow of resin sometimes appears in the second and third year of the life of a new infection on larch and yellow pine, which, if not fatal to the young plants, may seriously retard their growth for years. Until infection by actual inoculation, using natural methods, is attained, all statements of the ability of the parasite to effect an entrance in old-barked branches or trunks can not be accepted and must be considered faulty observation. The

writer has never succeeded in causing the infection of branches at any point older than four years. The ease of infection is found to be more or less in proportion to the decrease in age of the branches tested. This was proved in the case of yellow pine by inserting seeds at regular intervals in the axils of the leaf sheaths of young branches, from the terminal bud to the tenth internode. The results of this experiment are shown in Table III.



FIG. 5.—Four-year-old yellow-pine seedlings killed by mistletoe. Note the hypertrophy of the stem at the point of infection and the shortening of the needles. The two seedlings on the right were killed principally by having the wood and cambium in the swelling infiltrated with pitch. The parasite killed the seedling on the left by invading the terminal shoot.

TABLE III.—*Inoculation of Razoumofskyia campylopoda on Pinus ponderosa, made in November, 1911.*

[x=Inoculation effective; 0=inoculation not effective.]

Age of part of branch tested.	Seeds sown on each internode.	Results in November, 1914, on branch—				
		No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Season's growth.....	10	x	x	x	0	0
1 year.....	10	0	0	x	x	0
2 years.....	10	0	0	0	0	x
3 years.....	10	0	0	0	0	0
4 years.....	10	0	0	0	0	0
5 years.....	10	0	0	0	0	0
6 years.....	10	0	0	0	0	0
7 years.....	10	0	0	0	0	0
8 years.....	10	0	0	0	0	0
9 years.....	10	0	0	0	0	0
10 years.....	10	0	0	0	0	0

A study of Table III shows that the branches were infected in three out of the five test cases on the youngest and last internode on which the seeds were placed. Infection occurred on two of the five tested branches on that part 1 year old at the time of sowing, one infection only being on the 2-year-old portion. Infection did not take place on the older parts of the branches. A tree never becomes too old for infection to occur on its youngest branches. Suppressed trees may escape, owing to the fact that slowness of growth and more rapid formation of thick bark lessens the chance of infection; also shortness of twig growth gives less opportunity. The demand for a fair amount of light is also a factor in such a case, not, however, for the stages of germination and penetration of the primary root, but for the subsequent development of the aerial parts. Mature trees becoming infected on tender branches may not suffer any appreciable injury, but in time the decline of the tree is surely hastened, since the gradually increasing hypertrophy of the branches, the breakages, and the thinning out of the foliage of the tree as a whole cause it to be greatly weakened. Almost always the result of a heavy infection on the trunk and branches of some conifers is the death of the upper portion of the crown,¹ causing staghead (fig. 6),

¹ The dying back of the crown of trees, commonly known as spiketop, or staghead, is attributed to various causes; as many, in fact, as the varied conditions under which trees grow. One of the most common theories is that on opening up a stand the admission of light to the trunk and lower crown deflects the transpiration current to the older branch orders or, as with some species, promotes the formation of a secondary crown on the main trunk. This stimulated foliar activity below reduces the water supply at the top of the crown; consequently the topmost branches die back. This is exactly what happens in the case of mistletoes. The extra crown development below, by brooming, starves out the crown above, resulting in its death. Münch (Silva, December, 1911, pp. 415-416) claims to have found a parasitic Ascomycete which causes staghead in the oak of Europe by attacking the bark and outer wood of the main shoots. The writer has found a wood-destroying fungus which attacks the upper crown branches of the chestnut in southern Indiana and causes their death. The "pencil rot," which seems to be frequently the cause of staghead in the western red cedar, is another example of fungi attacking the crown of trees. Lightning is a common cause of staghead; also injury by insects.

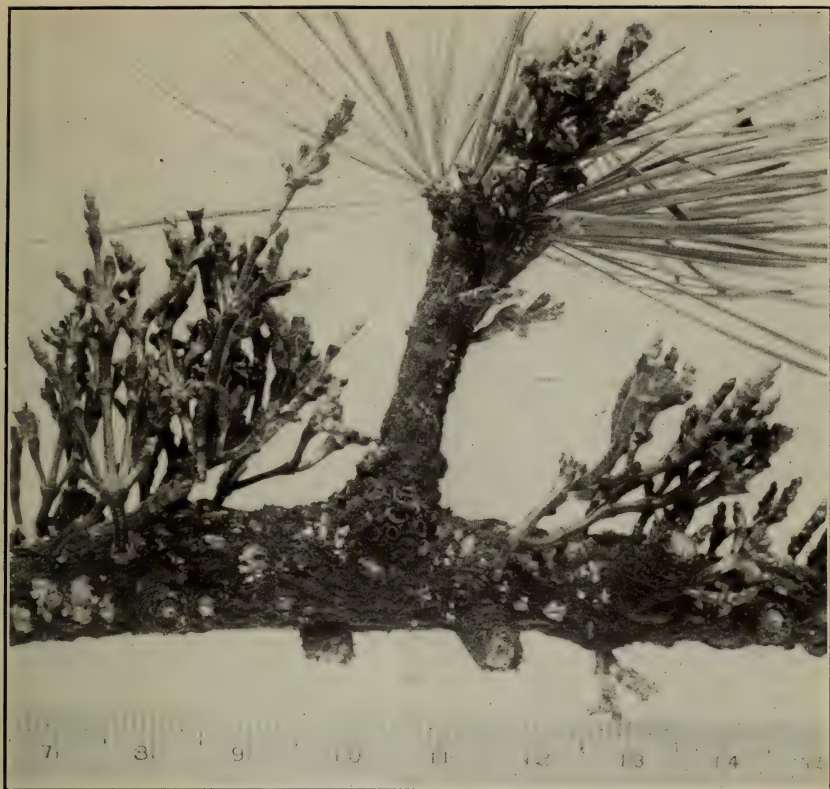


FIG. 1.—BRANCH OF *LARIX OCCIDENTALIS* INFECTED WITH *RAZOUMOFSKYA LARICIS*.
The staminate and pistillate plants are in close juxtaposition, the former at the end of the twig.

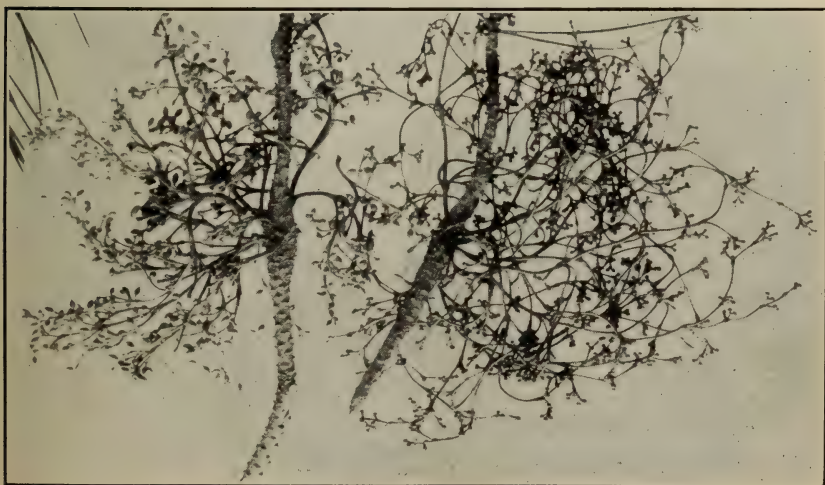


FIG. 2.—*RAZOUMOFSKYA AMERICANA* ON *PINUS CONTORTA*.
Staminate and pistillate plants; long trailing form.



FIG. 1.—*RAZOUMOFSKYA DOUGLASII* ON *PSEUDOTSUGA TAXIFOLIA*.
Staminate plants, slightly less than natural size.

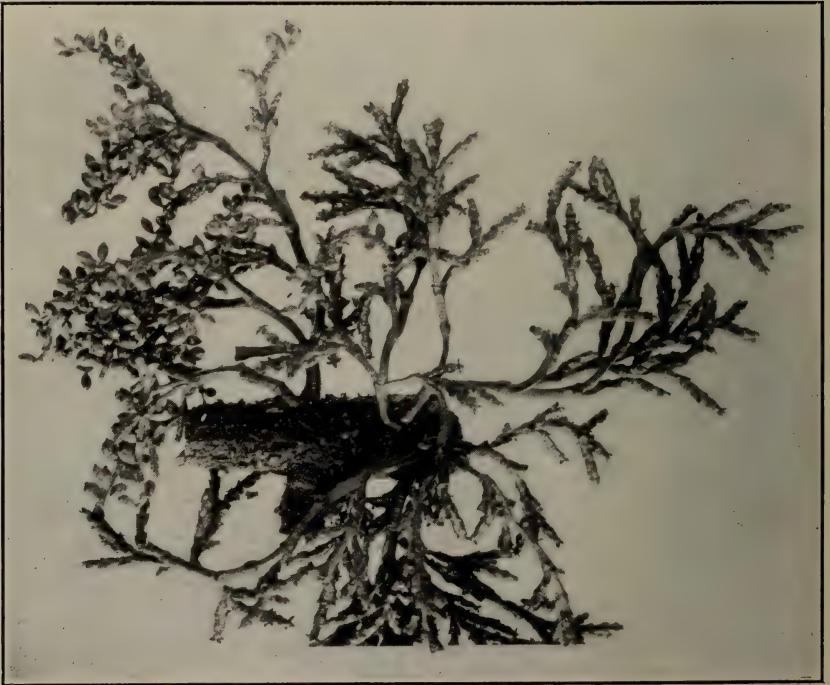


FIG. 2.—*RAZOUMOFSKYA CAMPYLOPODA* ON *PINUS PONDEROSA*.
The staminate and pistillate plants are growing close together on the same branch, a very common condition for all species, but not generally known.



FIG. 1.—AN OPEN STAND OF YELLOW PINE HEAVILY INFECTED WITH RAZOUMOFSKYA CAMPYLOPODA.

Note that some of the trees are dead and that others have very thin foliage. The structure of the dead brooms is plainly shown. Some of the trees bear burls on the main trunk. The young growth is seriously infected with mistletoe.



FIG. 2.—A HEAVY GENERAL INFECTION OF A 15-YEAR-OLD YELLOW PINE BY RAZOUMOFSKYA CAMPYLOPODA, RESULTING IN A DISTORTED AND OPEN CONDITION OF THE CROWN WITHOUT PRONOUNCED BROOMING.

The natural excurrent growth of the main trunk is entirely changed.



FIG. 1.—NEEDLES OF DOUGLAS FIR FROM A NORMAL BRANCH (AT THE RIGHT) AND OF A MISTLETOE BROOM ON THE SAME TREE, SHOWING THE DIFFERENCE IN SIZE.



FIG. 2.—YELLOW PINE AT THE HEAD OF A CANYON, SHOWING MISTLETOE INFECTION.

Note that the heaviest infection occurs on the immediate edge of the canyon and that the intensity of the infection decreases as the distance from the brow of the canyon increases; also that the upper crowns of the infected trees are becoming very thin.

or in some cases the entire tree may succumb (fig. 7 and Pl. III, fig. 1.) In many parts of the Whitman National Forest, wherever the heaviest infection of yellow pine occurs the percentage of dead or spiketopped trees reaches a comparatively high figure.

In a report to Supervisor Ireland, Ranger Smith, in referring to the seriousness of the infection of yellow pine in the vicinity of Susanville, Whitman National Forest, states that since 1907, the year in which the mistletoe damage in the region first received attention, the infection

of all age classes has been growing worse, probably 40 per cent of the stand now being infected. Of the more mature stand, approximately twice as many trees near the station as were noted in 1907 have since died. Ranger Smith further states that for a most pronounced general infection of all species the drainage basin of the South Burnt River particularly illustrates the devastating effects of mistletoes. "Almost every yellow pine from seedlings up and Douglas fir above sapling size is heavily infected and most of the mature timber shows great retardation of growth and is now adding little or no increment. This infection covers a large part of the best yellow-pine sites in the yellow-pine belt of this watershed." This region was not visited by the writer, but to judge from studies in other parts of the same forest Ranger Smith's observations are undoubtedly correct.



FIG. 6.—Douglas fir, showing the death of the upper portion of the crown caused by *Razoumofskyia douglasii*. The tree to the right with the series of immense brooms also has a dead top. A large broom had split off from the trunk of the tree on the left. All the young growth in the vicinity of these trees is seriously infected.

In order to determine the relative amounts of different species cut as snags on the W. H. Eccles Lumber Co. sale (Whitman Na-

tional Forest), the following figures were assembled by Mr. T. J. Starker, covering a period of 28 days of cutting:

Western larch	556
Western yellow pine	1, 221
Douglas fir	422
Total	2, 199

It must not be assumed that the death of these trees resulted from mistletoe. It is doubtful whether the death of even a small



FIG. 7.—Douglas fir killed by mistletoe. Note the total absence of normal branches. The structure of the brooms is here plainly shown. Note the straight trunk of the larch in the background. It is uninfected by mistletoe and still retains its original branches.

percentage of them, with the exception of the larch, can be so referred. A more conservative statement would be that mistletoe had a large share in their death by causing spiketop, the brooming of branches, and the formation of burls on the trunk. These are common forms of mistletoe injury for all three species in this region and lead up to serious insect infestation, of which more is said later. That mistletoes are capable of actually causing the death of their hosts is first shown by their effects on young growth from three to eight years old. In a heavily infected but very open stand of yellow pine on the bench lands of the Spokane River, Wash. (Pl. III, fig. 1), an attempt was made to ascertain the amount of injury resulting to the seedlings of an average

sample acre, which included in its area nine semimature and heavily infected trees in all stages of suppression. The acre was divided into plats and all young growth counted and examined as to infection and the condition of the infection. The number of seedlings and small growth below 8 feet in height totaled 480, which is an excellent reproduction for this region. Just a little more than half of this number, or 245, were found to be infected, representing every possible type of infection on stem and branch. It is not to be expected that these seedlings would ever grow up to form merchant-

able trees. Considering the severity of the infection, they could not be expected to attain near the size of their parents shown in Plate III, figure 1, and from which they received the mistletoe. Of the 245 infected seedlings, 49 were dead. An examination of the root system of each seedling showed it to be well developed. In the absence of any other deteriorating influence except an occasional needle infested by *Chionaspis pinifolia* Fitch, the death of these seedlings must be ascribed to the luxuriant growth of mistletoe which they had supported (fig. 5). In most cases the tufts of mistletoe had fallen away. The bark of the large fusiform swellings was usually ruptured and both the wood and bast tissues were so heavily infiltrated with pitch that the passage of food materials between the crown and the roots was wholly impossible, resulting in death. In this respect there is a parallel between this type of mistletoe injury to seedlings and that resulting from the perennial mycelium of some cauliculus *Peridermiums*.



FIG. 8.—A group of Douglas firs with their entire lower crowns developed into brooms by *Razoumofskya douglasii*. Note the sparse foliage of the upper crowns and the young brooms in the tree on the right, showing how the parasite travels upward. The branches between the brooms have died from lack of nourishment.

A further study of the large trees shown in Plate III, figure 1, is illuminating. Two of them, the right and the left in the figure, are dead. Scarcely a single normal branch is to be seen, but instead are numerous large gnarled and distorted brooms. These trees measured on an average 9.3 inches in diameter at $4\frac{1}{2}$ feet from the ground, and increment borings showed the age of each to be 190 years. This is far below the diameter of normal trees of the same age for the region. A careful search for secondary causes of injury resulted negatively. The trees were absolutely sound. Lightning injury, which sometimes causes spiketop in yellow pine and other conifers and which sometimes is erroneously attributed to mistletoe, was not present. With the evidence in hand, it is safe to state that the trees

were killed by the parasite. The other trees in the figure show various stages of suppression and an abnormal thinness of foliage. The tree on the extreme right shows midway on its trunk a typical mistletoe trunk burl.

It is often disputed that mistletoe is a cause of spiketop or that it is totally unknown for some species. The first and heaviest seat of infection in nearly all trees of economic importance is in the lower part of the crown (figs. 6 and 8). This is not necessarily a result of the seeds of the parasite falling first on the lower branches, but is rather the result of the fact that the main shoot continues for a time to grow in height, and the crown may attain its normal height before the effects of the parasite become dominant. The mistletoe spreads upward from the lowermost branches, with the result that the more recently formed branches are continually being infected. That these infections may not cause a brooming of the branches in the beginning is abundantly shown by the entire absence of any brooming on young infected branches of several host species. This, however, is only the first stage in the hypertrophy of the branch. After the lapse of several years, typical brooms are formed. With the increasing hypertrophy of the lower portion of the crown, food materials are more and more appropriated at this point. The result is a drain on the resources of the entire tree to support the brooms. Materials traveling upward from the roots are likewise utilized by the broomed branches, with the result that the upper portion of the crown starves and in cases of severe infection finally dies (figs. 5, 6, 7, and 8). Spiketop is an almost universal condition in heavily infected larch. The tendency to form spiketop in this species, however, is greatly augmented by the brittleness of its branches. Douglas fir probably comes next in order of frequency of dead tops resulting from the growth of mistletoes. The condition is common for yellow pine in all regions where observations have been made by the writer and is reported to be of frequent occurrence by correspondents in Utah and Wyoming. Lowland and mountain hemlocks, when heavily infected, quite commonly exhibit dead tops. An unusual case of heavy infection of the former species was studied in the St. Joe National Forest. Practically every tree in the entire stand was dead in the top (fig. 9). Lodgepole pine is less affected in this manner than any other conifer so far studied by the writer except spruce and fir. The last-named species are so seldom infected, however, that they would not enter into the discussion.

There can be little doubt that spiketop is very often the result of heavy mistletoe infection, but varies in degree for the several hosts. This condition is of importance, since the proportion of snags in the stand is thereby increased, which may promote injury by fungi and insects; it also increases danger from lightning fires.

With the conclusion of this general statement of mistletoe injury a more detailed discussion of the various types of infection will now be taken up.

RESULT OF INFECTION ON THE BRANCHES.

One of the first effects of infection, either of stem or branch, is the formation of a fusiform swelling (fig. 10). Sometimes this swelling is very pronounced and may resemble the enlargements caused by some species of *Peridermium* (fig. 11). The swelling is the first stage of the future hypertrophy commonly known as witches'-brooms. The absence of any pronounced brooming from early infections has led some observers to the conclusion that brooms are never produced on some conifers. Any change from the normal branching is here considered a broom. Still it is not necessary to draw such sharp lines, as the brooms produced by all mistletoes of the genus in question are quite typical. It may require several years for the broom to form. If young trees are generally infected they



FIG. 9.—Western hemlock (*Tsuga heterophylla*) infected by *Razoumofskyia tsugensis*. These trees do not possess a single normal branch. All are broomed. The trees in the background are spike topped. The tree in the foreground has had its growth in height arrested by an immense terminal broom.

sometimes assume an open, ragged appearance, which to the casual observer would not be considered a broom (Pl. III, fig. 2). Nevertheless, the tree is no longer excurrent. A similar condition is sometimes noted in more mature larches, where the infection is so generally distributed throughout the entire crown that no typical brooms are produced for years. Heavily infected branches of old trees of all species are seldom without brooming of some kind, and in most cases typical brooms are formed. The mistletoe plant may die out entirely on very old brooms, especially those of yellow pine

(fig. 12), but the stimulus to abnormal branching may continue. Brooms are formed on all hosts attacked by this genus of mistletoe.

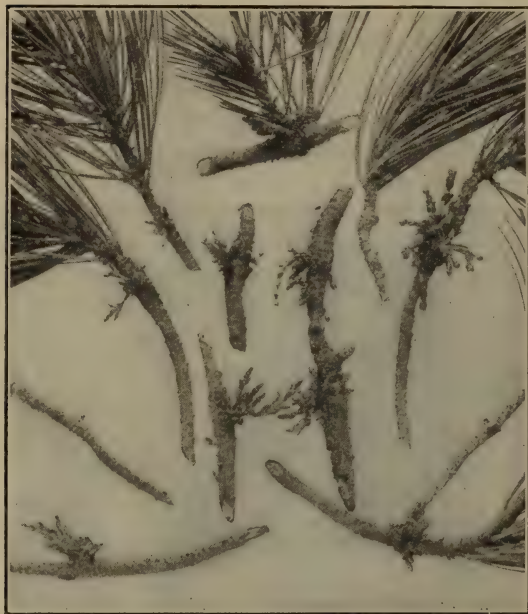


FIG. 10.—Young, first infections of *Razoumofskyia campylopoda* on western yellow pine (*Pinus ponderosa*).

Those of the yellow pine, owing to their loosely branched condition (fig. 12), are sometimes not as conspicuous as those produced on Douglas fir (figs. 6, 7, and 13), larch (fig. 14), hemlock (fig. 9), or lodgepole pine.

In all the regions where the yellow-pine mistletoe has been observed in the States of Washington, Oregon, Idaho, Montana, and South Dakota, brooming is a common result of the growth of the parasite on this tree.

Correspondents in Wy-

oming, Utah, and Colorado report that old infected trees are seldom without them. MacDougal (8)¹ refers to the excessive brooming of yellow pine by mistletoe in the Southwest. Meinecke (10) refers to the very conspicuous brooms on Jeffrey pine, sugar pine, yellow pine, lodgepole pine, and Douglas fir.

The old brooms of the Douglas fir, because of the long, trailing, willowlike branches of the lower portion of the broom, are more con-

spectuous than those of other conifers (fig. 13). They sometimes attain an immense size, often including the entire crown (fig. 6). In

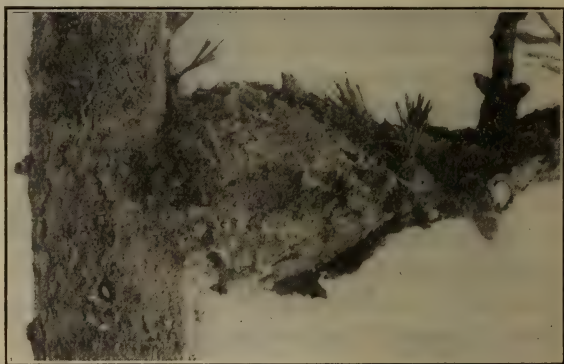


FIG. 11.—A larch branch, showing the result of a first infection at its base by *Razoumofskyia laricis*. This is the beginning of a burl at this point, which will spread to the main trunk.

¹ Reference is made by number to "Literature cited," p. 39.

most cases brooms are initiated on the Douglas fir soon after infection. Young seedlings frequently die in the top, owing to the formation of a lateral broom midway on the stem. In the heavily infected regions of Montana, especially in the Clark Fork (Bitterroot and Missoula Rivers) drainage, brooming of the Douglas fir is so universal and of such extent that scarcely a single infected tree is free from brooms of some type (figs. 6 and 7). The structure of these brooms is very plainly shown if the tree succumbs to the parasite, as it often does (fig. 7). The formation of brooms invariably results from mistletoe infection on the western larch. They may be situated on any part of the branch or at its base (fig. 14). In the latter case the entire branch eventually dies or is broken off by the wind, and its place is usually taken by a series of short, scrubby secondary branches forming a trunk broom. This broom eventually dies, leaving a large knotty burl of serious consequence not only to the life of the



FIG. 12.—Typical broom on yellow pine caused by *Razoumofskya campylopoda*. Note that the end of the branch is dead.

tree but greatly decreasing its value for lumber. Excessive brooming is a common feature wherever infected larch occurs and is the chief cause of injury to the species. In some localities in the Blue Mountains of Oregon and parts of Idaho and Montana, where this mistletoe is common, a normally formed larch is seldom found. Instead of the symmetrical, conical crown so characteristic of the normal tree, the crown develops under the influence of the parasite into a denuded spike, bearing only a few ragged branches. When it is recalled that practically every larch in these regions, from pole size up, is more or less infected and seldom attains a normal size, in many cases being killed outright, some notion may be had of the seriousness of the effects of the parasite on its host.

The brooming of the branches of the lodgepole pine by mistletoe is as characteristic as for the other hosts mentioned. Frequently the entire tree is involved, but more often only the lower branches. A few instances have been noted where the parasite hung in long festoons from the several infected branches

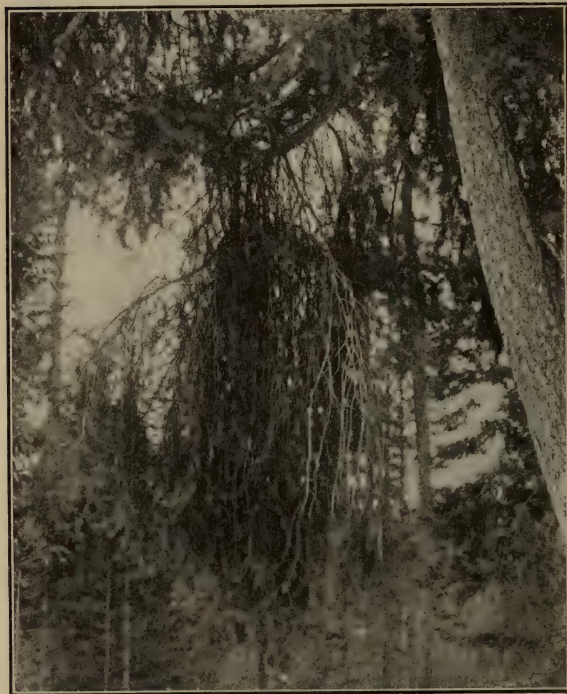


FIG. 13.—Typical broom of the weeping-willow type on Douglas fir caused by *Razoumofskyia douglasii*. Note the long, flowing branches. Sometimes these branches are 8 to 10 feet long.

without any particular hypertrophy of the branch as a whole. This condition is more apt to occur in dense stands. Observations by the writer on *Picea engelmanni*, *P. mariana*, *Abies grandis*, *A. lasiocarpa*, *A. concolor*, *A. magnifica*, *Tsuga heterophylla*, *T. mertensiana*, *Pinus monticola*, *P. albicaulis*, *P. flexilis*, *P. attenuata*, and other conifers show that brooming of the branches is a common phenomenon attending mistletoe infection of these species.

The weight of these brooms on many conifers is frequently sufficient under stress of winds and rain to cause the branches to split from the trunk, or to break farther out if the brooms are located far out from the trunk. This very commonly occurs in the case of



FIG. 14.—Typical brooms of old infections on western larch caused by *Razoumofskyia laricis*. Very few of the original branches remain, and they are heavily broomed and covered with lichens. The old branches are replaced by short scrubby secondary branches. Note that two of the original branches still remain, but are dead.

yellow pine and Douglas fir (fig. 15) and is the rule for larch. The stunting effect of these brooms on the trees as a whole was in one instance very interestingly shown by the fact that a middle-aged Douglas fir increased the radial dimensions of its annual rings after the removal by the wind of an immense broom located midway on the trunk. The weight of the brooms on some conifers is very often greatly increased by the accumulation of dead needles, lichens, etc. (fig. 14). When loaded with snow or saturated with moisture the

brooms are more easily broken off by high winds. The ground around the base of heavily infected larches is very frequently littered with brooms broken off in this manner, often insuring the death of the tree in case of ground fires. During the early part of October, 1914, an unusually heavy fall of soft snow occurred locally over a small area around Missoula, Mont. The snow accumulated in such quantities on the mistletoe brooms of the larches and Douglas firs throughout the

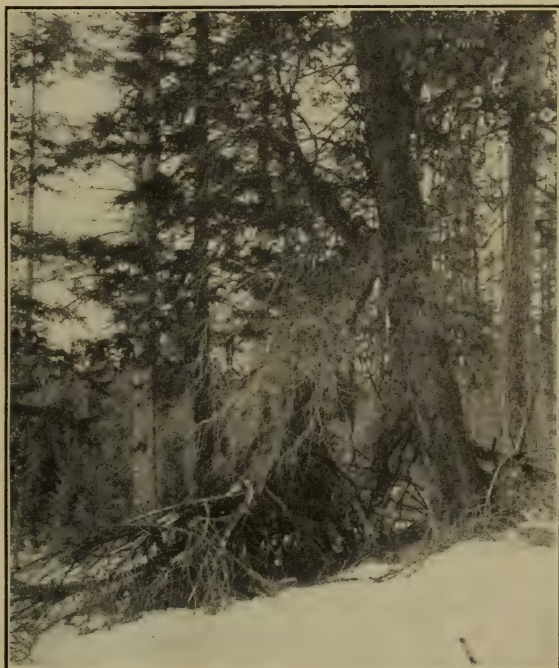


FIG. 15.—Fallen brooms split from the trunk of a Douglas fir and piled about the base of the tree—a serious fire menace.

area that the ground around the more heavily infected trees was piled high with fallen brooms.

The foliage of old and mature mistletoe brooms is usually not as long lived as that of normal branches of uninfected trees. This is not true in the case of young well-nourished brooms. It has been observed to any extent only in old brooms which have begun to tax the food supply of the tree or the branch on which they are located. In the course of one year it was determined that 655 more needles fell from a small but mature broom on a Douglas fir than from a normal branch of a neighboring uninfected tree of the same species. The number of needles falling from the broom totaled

976, from the branch 321. On very old brooms of the western larch it is often noticed that the needles begin to turn yellow some time before those on the branches of uninfected trees. Exactly the reverse may occur in the case of recently formed brooms, owing to the larger amount of newly stored food materials in the swelling on the main branch and the branches of the brooms. That the broom may be the cause of a great localization of food substances is indicated by the fact that in heavily infected Douglas fir and larch the last part of the tree to succumb is usually the smaller and younger brooms of the tree. Frequently trees of these species are noticed with only a single small broom living, the rest of the branches being apparently dead; likewise the old and exhausted brooms. The increase in the number of needles on the broom due to the multiplication of its branches is usually at the expense of the needle development on the normal parts of the tree. For this reason an excess of food materials for the tree as a whole does not take place. The foliage beyond the broom becomes thin and, in most cases, the end of the branch dies (figs. 12 and 14). The food materials are entirely stored and appropriated by the broom itself. The phenomenon is analogous to the formation of spiketop of the main trunk.

That brooms do not always necessarily mean an increase in foliar surface for the host, since we have seen that parts of the branches not supporting brooms frequently die, is shown by a comparison of the needles of old brooms with those of normal branches either of the same tree or of uninfected trees. Such a study was made in the case of the Douglas fir. It was found that the needles of the brooms on the trees studied were uniformly a little less than one-half as long as the leaves of the normal branches (Pl. IV, fig. 1). Neither were they as thick or as broad. By compensation it would be possible to determine approximately the actual foliar surface of a given broom and compare it with that of a given normal branch of the same whorl and of the same age. This difference in the size of the needles was found to hold good only in the case of old, mature brooms of trees which were beginning to be suppressed. Young brooms, especially on young trees from 10 to 20 years old, often have abnormally long needles on the still upright branches, but this condition is not long maintained. Soon these branches begin to droop, the broom becomes denser, the needles disappear from the center outward, and they are often sparingly distributed along the stems but more densely assembled on the last few years' growth (fig. 13). With continued suppression of the Douglas fir and exhaustion of the broom, a new type of branching often appears. The long trailing, weeping-willow-like branches cease to elongate and the cortical stroma of the parasite is enabled to catch up with the terminal bud and kill it. The branch

ceases to grow in length and instead forms abnormally abundant lateral branches. The terminal buds of these are likewise overtaken by the parasite, resulting in additional lateral branches, and so on, until a type of dichotomous branching results. This is more noticeable in the compact type of broom than in the long, trailing type, but is quite common in both, especially on exposed and wind-swept areas.

A very interesting hypertrophy of the foliage spurs is often shown by the brooms of the larch. The spurs are frequently abnormally large and may be four or five times as long as those of normal branches (fig. 16). On such spurs the needles are usually shorter and sparingly clustered. Eventually the parasite enters the spur and kills it. Not infrequently a mistletoe plant is found growing out at the apex of the spur or from its side, causing great distortion and the total disappearance of the needles, and eventually the death of the spur. The reduction of foliage by the thinning and shortening

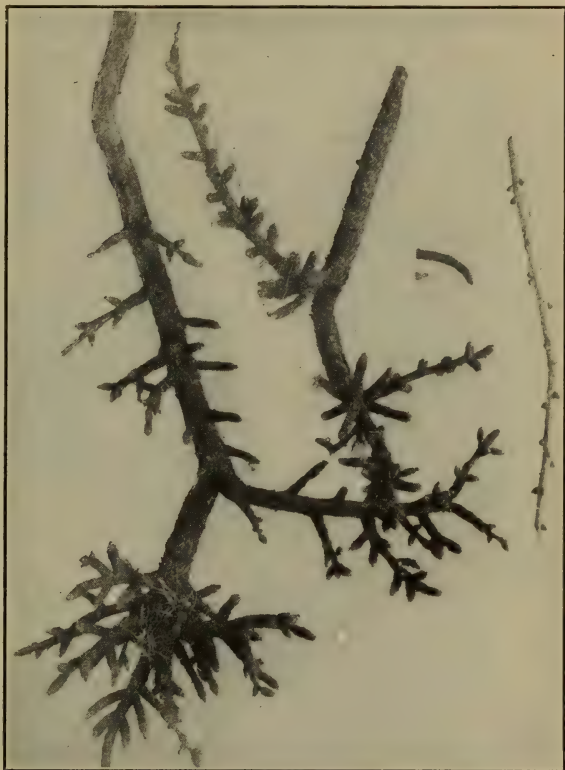


FIG. 16.—Abnormal foliar spurs of the western larch caused by *Razoumofskyia laricis*. Note their size as compared with normal spurs.

of the needles of the trees as a whole, and of the brooms sooner or later, is characteristic of mistletoe infection on all hosts.

The food material, which undoubtedly is accumulated in the brooms, seems to be entirely appropriated at these points and does not serve the host as a whole. The support of the excessive number of branches is necessary, but the parasite itself undoubtedly appropriates a large share at the expense of the healthy branches. The yellow-pine mistletoe has been observed to become more luxuriant and to develop abnormally long stems on swellings which had been lacerated or gnawed by rodents. Evidently the accumulation of

extra food materials in the healing tissues at this point exercised a beneficial influence on the parasite.

The actual nutritive relation between these parasites and their hosts is not at present well understood. The constant removal of all the needles of six lodgepole pines 8 to 12 years old on which large clumps of mistletoe were attached has not in the second year of the experiment resulted in the death of either the host or parasite. The controls, viz, six young pines of the same age, stripped of their needles but bearing no mistletoe plants, have died. This experiment indicates a possible transfer between the host and parasite not only of water and inorganic salts, but of organic food materials as well. However it may be interpreted, it seems that the pines were kept alive temporarily by the mistletoe. Probably it is a mutual subsistence on stored materials. It must be remembered that the whole tendency of the activities of these mistletoes (*Razoumofskya* spp.) is to reduce the life functions of the host to their lowest point, and this is the fact that should be of chief concern to the forester.

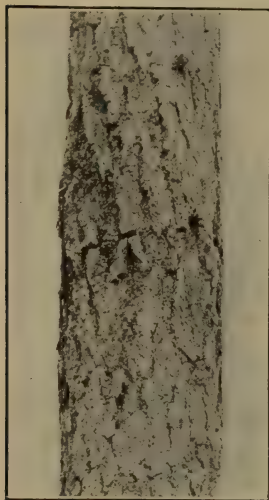


FIG. 17.—Area on the main trunk of a yellow pine infected by *Razoumofskya campylopoda*. The rough, irregular bark indicates the location of the burl tissues. A few short mistletoe plants not visible in the illustration were present.

RESULT OF INFECTION ON THE TRUNK.

Another form of mistletoe injury results when infections occur during the early life of the tree, with the formation of burls on the trunk. No case is on record of any member of the genus *Razoumofskya* effecting an entrance to its host through the mature cortex. If apparently recent infections on old parts of trees are carefully examined, the mistletoe plant will be found to have persisted from the time when the branch or trunk was young. Until it is proved by

actual inoculation that the parasite is able to penetrate the mature cortex with its outside covering, commonly called the bark, the foregoing statements must remain valid.

Burls on the trunk caused by mistletoe are very common for some hosts, but vary in frequency on others. In point of frequency the western larch is most seriously affected by this kind of injury. Two types of burls occur on this tree, determined by the nature of the original infection. If the infection occurs at the base of a branch (fig. 11) and travels to the main trunk, a basal branch burl results, giving rise to a broom, which later dies, leaving a great burl, often of large proportions. If infection occurs directly on the main trunk the beginning of a trunk burl is immediately initiated. With

the increasing age of the host the burl tissues radiate outward in a fan-shaped area when viewed in cross section and soon leave an open wound, through the death of the central part of the infected wood. These two types of burl are so common on larch in mistletoe regions that the quality of the wood is seriously injured, resulting in a large amount of cull. In the several regions studied by the writer mistletoe burls on yellow pine are frequent. In one section of the city park at Coeur d'Alene, Idaho, are 30 or 40 large, old yellow pines. About half of the trees have mistletoe burls on the first



FIG. 18.—Cross section of a mistletoe burl on the yellow pine shown in figure 17. (The tape shows feet in tenths.)

log length and in most cases the parasite is still living in them, with a few scattering short aerial parts. Similar conditions prevail throughout the Spokane River Valley and around Coeur d'Alene Lake. Mistletoe burls on old yellow pine may or may not be conspicuous. Frequently there is no pronounced swelling (fig. 17) and sometimes the only means of detecting the diseased condition is by the presence of the mistletoe or an unusual roughness of the bark. A section through the tree at this point, however, shows the curly grain and the old roots of the parasite extending to the point of original infection (fig. 18). These burls are often very conspicu-

ous, large barrel-shaped swellings, from which pitch usually exudes in large quantities. Infection on one side of the tree generally results in the type of burl shown in figure 19.



FIG. 19.—Common type of burl on yellow pine caused by *Razoumofskyia campylo-poda*. The tree is 3 feet in diameter at this point.

on western hemlock wherever the parasite occurs in quantity. The same is true for the mountain hemlock. In the Marble Creek region of the St. Joe National Forest mistletoe burls on the hemlock are of frequent occurrence. Allen (1, p. 20–21) writes of this type of injury as follows: "If, however, the plant gets foothold on the leading shoot, a burl follows which persists throughout the life of the tree and not only ruins a log, but renders the tree apt to be broken by the wind." Infection on the main trunk of lodgepole pine is often attended by long fusiform swellings as the parasite progresses from the original point of infection. This may continue until the bark becomes so hard that the plants can not push up through it and the spread of the parasite ceases (fig. 20). The parts

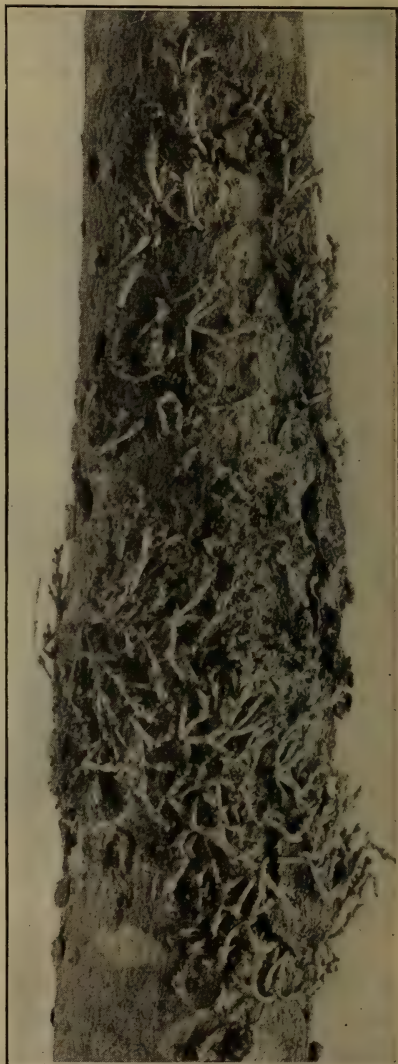


FIG. 20.—Main stem of a lodgepole pine infected by *Razoumofskyia americana*. Note the spread of the parasite from the original point of infection. The bark at this point very frequently dies, leaving an open wound. (Photographed by George G. Hedgcock.)

infected, however, may continue to produce aerial branches of the mistletoe to a very advanced age. True mistletoe burls are probably of less frequent occurrence on Douglas fir than on any other economic tree species. Burls do occur, however, with sufficient frequency to be characteristic of mistletoe infection on the trunk of this tree. Large elongated mistletoe burls, including the entire circumference of the trunk, occasionally occur in heavily infected trees in many parts of Idaho and Montana (fig. 21). More frequently there is a series

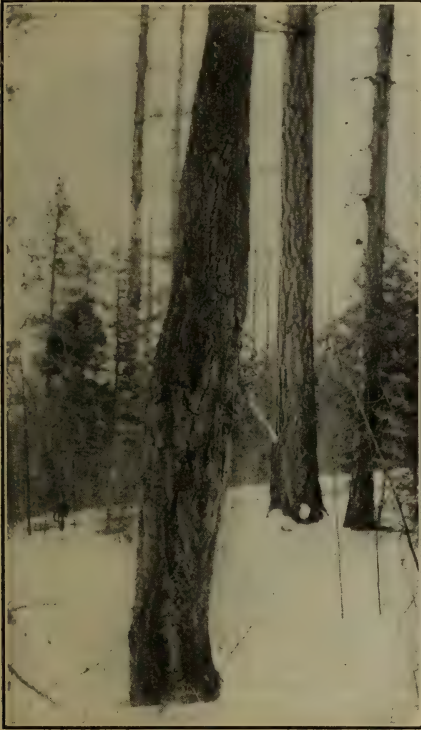


FIG. 21.—Large mistletoe burl on Douglas fir caused by *Razoumofskya douglasii*. This burl is approximately 10 feet long and 2 feet in diameter at its widest part.



FIG. 22.—A Douglas fir, showing numerous burls caused by *Razoumofskya douglasii*. The branches are heavily broomed. A high degree of infection, but a common condition, is shown.

of individual burls, more or less confluent, on one trunk (fig. 22), each burl representing the seat of an old infection, from which the aerial parts of the parasite have long since disappeared. Longitudinal and cross sections through these burls show the characteristic fan-shaped areas of infection (fig. 23). In numerous cases the burls originate from infections at the base of branches. If the branch dies or is broken off, an open wound is formed in the center of the burl. Very peculiar swellings or small burls frequently occur on

the branches of brooms. These are sometimes so numerous as to cause the branch to resemble a chain of spherical balls. Mistletoe infection on the trunks of spruces in the East often results in the formation of burls; also on the western firs. It can be safely stated that swellings and distortions of the main trunk which persist throughout the life of the tree are a characteristic feature of mistletoe infection on most conifers of economic importance.

The spread of the burl tissues tangentially and longitudinally, which, as previously indicated, are frequently inhabited by the



FIG. 23.—Cross section of one of the burls on the Douglas fir shown in figure 22. This section does not pass through the point showing the age at which the infection first occurred. (The tape shows feet in tenths.)

parasite until a very advanced age,¹ results, as is the case with most species, in cutting off the transporting tissues and hastens the decline of the tree (figs. 20, 23, and 24). The bark and wood of the

¹ Meinecke, in 1912 (9, p. 38), records the age of a mistletoe plant (*Phoradendron juniperinum libocedri* Engelm.) at approximately 230 years. Species of the genus Razoumofskyia are likewise capable of maintaining themselves to a very advanced age. One instance recorded by the writer may be cited of *Razoumofskyia campylopoda*. A cross section through a mistletoe burl of this species, 3 feet from the ground, on yellow pine—a position precluding any but an original infection at an age when the bark was thin—showed that the parasite had continuously lived in the burl tissues for 340 years. The old roots, now dead except those immediately next the cambium, could be readily traced to the point of original infection. The age of the tree at this point was three years. The burl bore a single fertile aerial branch of the mistletoe. The greater mass of the cortical stroma was entirely without aerial parts, indicating the remarkable condition of parasitism first pointed out by Meinecke for *Phoradendron juniperinum libocedri*.

outer central area of the burl die soon after the death of the cortex, especially in burls on the larch, and open wounds are formed, inviting the attack of forest-tree insects and wood-destroying fungi (fig. 24). The abnormal thickness and the soft, spongy consistency of the inner bark of mistletoe-infected branches are attractive to various gnawing animals; they are also an index of the storage of food materials at this point (fig. 25).

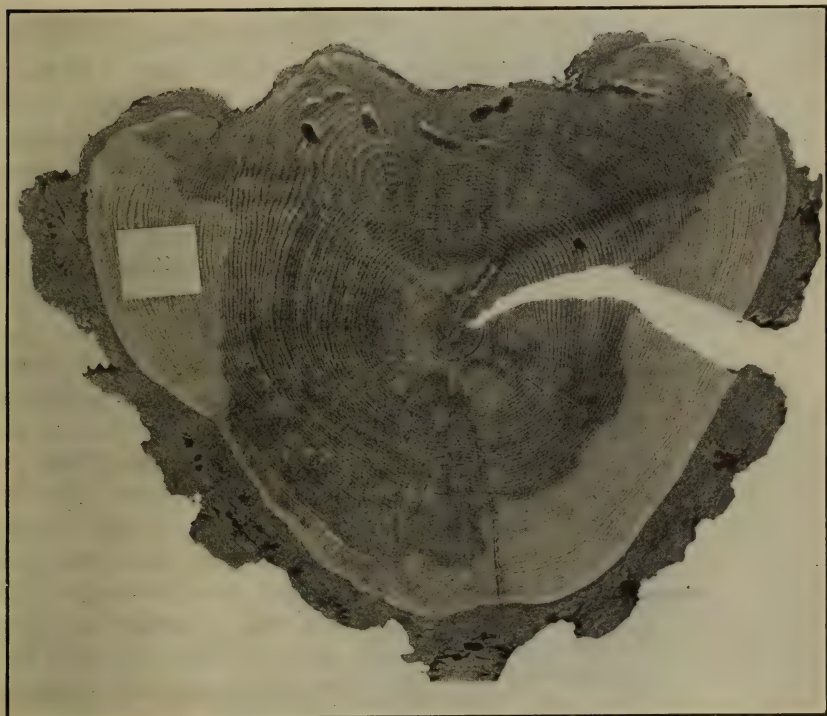


FIG. 24.—Cross section of a burl on a western larch caused by *Razoumofskyia laricis*. Diameter of burl, 2 feet. Note the presence of borers and fungi. The check appeared in seasoning.

RELATION OF MISTLETOE INJURY TO FUNGOUS ATTACK.

Some very interesting data have recently been assembled by the writer on the relation of mistletoe burls to fungous attack. From cutting areas on the dry bench lands of northern Idaho, 540 mistletoe-infected living larches were examined. Out of 600 mistletoe burls found on these trees, 278 were inhabited by serious wood-destroying fungi and other unimportant species. According to frequency of occurrence the most important of these fungi are *Trametes pini* (Brot.) Fr., *Fomes laricis* (Jacq.) Murr., *Polyporus sulphureus* Fr. (four occurrences at 20 feet up on the trunk, a very

unusual habitat), *Trametes serialis* Fr., and *Lenzites sepiaria* Fr. *Fomes pinicola* Fr. was found rotting the heartwood of living trees in three different cases and had entered its host through mistletoe burls 10 feet from the ground. *Polyporus volvatus* Pk. occurs frequently on the burls of larch and yellow pine. Several species of Thelephoraceæ were collected from the mistletoe burls, chief of which



FIG. 25.—The soft spongy cortex of a mistletoe infection on lodgepole pine gnawed by rodents. This is a very common type of injury in mistletoe-infected trees.

were *Stereum sulcatum* Burt, *Corticium berkeleyi* Cooke, *C. galactinum* (Fr.) Burt, and *Peniophora subsulphurea* (Karst) Burt. *Ceratostomella pilifera* (Fr.) Wint., the bluing fungus, appeared occasionally in the dead wood of the burls. *Trametes pini* affected 80 per cent of all burls attacked by fungi. Since the most advanced stages of decay were always at the burl or in its near vicinity, it was assumed that the fungi had entered at this point. The decay at or in the burl tissues was in most cases not connected with the decay which is often present in other parts of the trunk. The breakage of old branches possessing heartwood, through the accumulation of brooms at their outer extremities, is likewise a means of fungi entering the tree. Not infrequently *Fomes laricis* enters its host by this

means. Mistletoe burls on Douglas fir are known to become infected with *Trametes pini*. A mistletoe burl on Alpine fir was found to be inhabited in one instance by *Pholiota adiposa* Fr. Meinecke (10, p. 58) refers to the mistletoe cankers of *Abies concolor* as offering an easy entrance to germinating spores of *Echinodontium tinctorium*. Burls on yellow pine, owing to their resinous condition, are seldom attacked by wood-destroying fungi. The bluing fungus, however, has been found by the writer in the distorted tissues of mistletoe burls on living yellow pine.

GENERAL SUPPRESSION AND FUNGOUS ATTACK.

Aside from the fact that fungous enemies enter these conifers through broken branches, lesions, and burls caused by mistletoe, heavily infected trees are, owing to their weakened condition, more susceptible to fungous attack on any part—roots, trunks, or leaves. In the lake region of Idaho the larch of all ages and conditions is at present suffering from an epidemic of a needle disease, *Hypodermella laricis* Tub. It is observed that in practically every instance the needles of very old mistletoe brooms are first attacked, whereas those of the uninfected trees of particular age classes or exposures may ward it off for a longer period.¹ It is a common observation that in regions of heavy mistletoe infection (and nowhere is it better shown than in the forests of eastern and central Oregon and many parts of Idaho and Montana) many heavily infected trees are in a dead and dying condition. If these trees are carefully examined with reference to average healthy growth for the region, it will be found that they have died prematurely.

It has already been indicated that mistletoe is capable of causing the death of its host in some instances. The whole tendency of the parasite is to reduce the life functions of its host to the lowest point, and if death does not result from this cause alone the way is opened to various secondary agents, which may or may not attack vigorously growing trees. The gradual thinning out of the foliage of heavily infected trees and the appropriation by the brooms of much of the elaborated food materials must necessarily result in an unbalanced relation between the crown and the root system. Consequently, there may be a dearth of food materials for the latter, wholly inadequate to support its present extent. It may be naturally inferred that this results in the suppression of the roots or a dying off of the more extended members of the system. A close examination of a hundred or more windfalls of heavily infected Douglas fir, yellow pine, and larch in the regions above mentioned shows quite clearly that the horizontal and brace roots of these trees in most cases were badly decayed. Since few windfalls of the heavily uninfected trees of the same average age and size were observed in the same region, it may be inferred that a possible relation existed between the suppressing effects of the mistletoe and the decay in the roots. *Armillaria mellea* (Vahl.) Quél. was definitely associated with some of the decay in the roots. In most cases, however, owing to the absence of fruiting stages, the cause of the rot in the fallen trees could not be determined.

¹ *Hypodermella laricis* was first named and described by Von Tubeuf on the European larch (*Larix europaea*). This is the first note of its occurrence in North America. The fungus, characterized by its four clavate spores to an ascus, is very destructive and is the cause of considerable damage in the larch forests of the northwestern United States and Canada.

It is a well-known fact that wounds heal quickly in young or in strongly growing trees, principally due to the protection afforded by an abundant flow of resin. It may be assumed that trees having their life functions brought to a low ebb by excessive mistletoe infections, with resulting decrease in annual increment, will not be able to heal or protect their wounds as quickly as normal trees; hence, are more liable to infection. This may be one of the reasons why so many open burls are formed on infected larches. These open burls are seldom, if ever, healed, although the parasite in its tissues has long since died. There is a slight increase in the number of resin passages in early burl formations, but this is entirely offset by the early dying out of the bark of the burl exposing the wood. It is an observed fact, experimentally proved by the writer, that strongly suppressed yellow pine, larch, and Douglas fir do not as readily form traumatic wood or exude the normal quantity of resin on being wounded on any part as do normal, healthy trees. Such a tardy reaction to injury does not afford a ready antiseptis against the entrance of fungi which may attack these trees. Since turpentine orcharding is becoming more extensively practiced in the West it would be an interesting experiment to determine the relative flow of pitch from trees strongly suppressed by mistletoe and from those in a high state of health.

RELATION OF MISTLETOE INJURY TO INSECTS.

In the same manner that burls and other types of mistletoe injury on some conifers are open doors to fungi, they are found to afford a ready means of entrance for some species of forest-tree insects which do not in this region habitually attack vigorous unwounded trees. Old mistletoe burls on larches are almost invariably attacked by borers (figs. 23 and 24), and burls on yellow pine are, in the experience of the writer, quite as frequently infested by bark and wood boring beetles. In this connection a very curious and interesting phenomenon often occurs on young yellow pines from 10 to 20 years of age. An infection by mistletoe will have occurred, completely enveloping the trunk some 2 or 3 feet from the ground. The parasite having advanced somewhat each way from the point of original infection, the intervening space is attacked by *Dendroctonus valens* Lec. The combined influence of the beetle and mistletoe results in the complete infiltration with resin of the space between the two edges of the advancing mistletoe, so that the cambium dries out and dies. Strange to state, this does not always kill the tree. The crown goes on manufacturing food materials, being supplied with water through the inner wood of the girdled area. The elaborated food not being able to travel downward, since the cambial tissues of the entire circumference of the stem have been destroyed, is stored just above the

girdled area and initiates an abnormal swelling (fig. 26). The swelling continues to increase in size and weight, likewise all members of the crown, so that eventually the slender stem below can no longer support the overdeveloped crown and is broken down by the wind. A specimen in the laboratory shows the number of rings of the stem at the girdled area at the time it was cut to be eight, with a diameter of 1 inch. The swelling just above and within the same internode showed 15 rings, with a diameter of 3 inches. The same phenomenon is sometimes produced in yellow pine by *Peridermium filamentosum* Pk. When it is recalled that the cambium and the outer wood of the girdled area are actually dead, the length of time the crown continues alive is really remarkable.

In point of general insect attack it has been noted that the beginning of an infestation may start with trees badly suppressed by mistletoe. The fact that trees heavily suppressed by mistletoe have a weak flow of sap causes them to be first selected by certain forest-tree insects. For this reason mistletoe areas form centers from which infestations may spread. Again, numerous infestations may start simultaneously over a wide territory, owing to the weakening of the trees by these parasites instead of from a few detached areas, as is often the case. This has been found particularly true in the case of yellow pine and the red turpentine beetle mentioned above. In all regions of heavy mistletoe infection of the Douglas fir, *Dendroctonus pseudotsuga* Hopk. is usually very abundant. This was the rule in the Whitman National Forest, Oreg., and though the numerous dead trees of this species in the forest were undoubtedly the result of an immediate attack by the beetles, their work was hastened, it seemed, by the serious mistletoe suppression which was exhibited by most of the dead trees. During the season

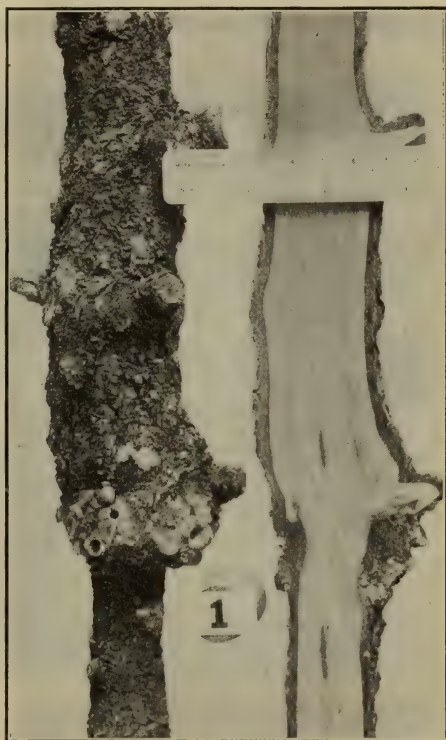


FIG. 26.—A young yellow pine, showing complete girdling of the stem by a combined attack of mistletoe and insects. The cambium is destroyed, but the crown remains alive and continues to elaborate food materials, which are stored just above the girdled area.

of 1914, a large number of badly suppressed Douglas firs on the foothills bordering the Clark Fork (Missoula River) Valley have died from a combined attack of mistletoe and beetles. Most of these trees, which supported scarcely a single normal branch, had the bark of limbs and trunk almost entirely removed by woodpeckers in their search for the beetle before the leaves were entirely dead. The few uninfected Douglas firs of the same region have not been attacked by the beetles.

The branches of large mistletoe brooms on yellow pine and Douglas fir from which the parasite has entirely disappeared are very



FIG. 27.—Seats of original mistletoe infection on two living branches (in center and at left) of mistletoe brooms on yellow pine infested with bark beetles. No other part of the broom or tree was attacked. Main stem of young living yellow pine (at right) attacked by bark beetles at the seat of an old mistletoe infection.

frequently found infested with bark beetles (fig. 27), while the trunk and normal branches of the trees are entirely free from attack.

INFLUENCE OF MISTLETOE INJURY ON THE SEED PRODUCTION OF THE HOST.

Germination tests of seeds of yellow pine taken from mistletoe-infected trees show that the percentage of germination is considerably lower than is the case with seeds taken from normal trees (12, p. 7). Experiments conducted by the writer with seeds taken from cones produced on very old mistletoe brooms of Douglas fir, larch, and lodgepole pine showed a germination on an average of 10 per cent below that of seed taken from uninfected branches of

the same trees. Given the general average percentages of germination of 30 for the former and 40 for the latter, it seems that either from exhaustion of stored materials or tendencies toward abnormal seed production in general the uninfected branch, though suppressed, is still capable of producing a higher quality of seed than the broom. Whether this would be true in the case of young, vigorous brooms is doubtful. Seeds from the uninfected branches of the same strongly suppressed trees used in the above experiment gave a general average of 15 per cent below that of seeds taken from vigorous uninfected trees of the same age, species, and habitat. The percentage of 65 for the uninfected and 40 for the infected shows quite clearly that suppression by mistletoe causes a serious falling off in the quality of the seed of its host.

The experiment was conducted in the following manner. Collections of cones were made from each of five strongly suppressed and five uninfected trees of all three species. This included one collection from the brooms, one from the uninfected branches of each of the suppressed, and one collection from each of the uninfected trees; in all, 45 different collections. One hundred seeds were extracted from each collection and germinated in sand at an average temperature of 35° C. Counts were made at different intervals during the progress of the test, which was continued for 90 days. Considerable difficulty was experienced in procuring the required number of seeds for all conditions, owing to the sterility of the cones on the old brooms. With the increasing age of the broom the seed production falls off, until, as it is with most species, no cones are produced at all. Seeds from recently formed brooms were not tested. It is supposed that they would show a higher percentage of germination. The cones on badly suppressed trees are very often aborted, with shriveled, undeveloped sporophylls, and are frequently infested by cone beetles and cone worms. Seeds, if produced in such cones, are usually below the normal size. A study of microtome sections of the staminate flowers from heavily infected lodgepole pine showed that there was a reduction in the number of pollen mother cells. The staminate flowers when compared with those of normal trees of the same age and condition were found to be uniformly smaller. The sporophylls on the more fertile or convex side of the young pistillate cones very frequently bore only one ovule (megasporangium), a condition not observed in cones from healthy trees.

HOST AFFINITIES IN RELATION TO SILVICULTURE.

For practical purposes the following statements on the host requirements of the mistletoes of coniferous trees will be found to be of some interest with regard to the silvicultural management of forests.

Razoumofskya douglasii (Engelm.) Kuntze is of economic importance only on the Douglas fir. The affinities of the very small and rare forms of *Razoumofskya* on spruce and fir,¹ described by Engelmann (6, p. 253) under the name of *Arceuthobium douglasii* var. *microcarpum* for the former host and *A. douglasii* var. *abietinum* (3, v. 2, p. 106) for the latter, are not definitely established. In point of time of blooming and seed maturity, it coincides with that of *Razoumofskya douglasii* for northern regions, and their form and color are quite similar, especially the color of the staminate flowers. These small plants, together with the Douglas fir mistletoe, are the only members of the genus exhibiting a pronounced color of the lobes, which are a bright, deep purple. Until cross-inoculation experiments are perfected, these particularly small mistletoes on spruce and fir may be considered wholly unimportant from a silvicultural standpoint. For the sake of convenience, they may be placed with the Douglas fir mistletoe and the whole designated as the *Pseudotsuga-Abies-Picea* group, characterized by their small size and colored flowers. *Razoumofskya laricis* Piper, the most universally distributed and probably the most injurious of the entire genus, is associated with the western larch. This species in a single instance has been collected by the writer on lodgepole pine near Missoula, Mont. It is a significant fact that this infection is not vigorous and appears to be dying out. *R. americana* (Nutt.) Kuntze is more strictly associated with the lodgepole pine, but is the cause of serious damage to the jack pine (*Pinus banksiana*) where these two species approach each other in Canada. *R. tsugensis* Rosend., as far as observations in the field have gone, is confined to the hemlocks.

The remaining species of importance may be divided into two main groups, a fact that has not been heretofore set forth, viz, those associated with the soft or white pines and those attacking the hard yellow pines. It seems that the members of one group are not in a single instance associated with the hosts of the opposite group. The former group includes the following species and hosts: *Razoumofskya divaricata* (Engelm.) Coville on the nut or piñon pines, *P. edulis* and *P. monophylla* (6, p. 253); *R. cyanocarpa* A. Nels. on *P. flexilis* (4, p. 146), *P. albicaulis*, and *P. monticola*. *Pinus monticola* has not been previously reported as a host for these parasites. *Pinus strobiformis*, the Mexican white pine, is reported (11, p. 65) as the only host of *R. blumeri* (A. Nels.) Standley. The second group may be included by the two-form species: *R. campylopoda* (Engelm.) Piper and *R. cryptopoda* (Engelm.) Coville. The former is principally injurious to *Pinus ponderosa*, but is common on *P. attenuata* (7, p. 366; 13) and *P. jeffreyi* (10, p. 38). The latter is likewise an injurious parasite on

¹*Abies concolor* is also host for *Phoradendron bolleanum* (Seem.) Eichl. (5, p. 193).

P. ponderosa, but occurs on *P. jeffreyi* (5, p. 192), *P. arizonica* (2, p. 243), and *P. mayriana* (2, p. 243). *R. campylopoda* has recently been collected by the writer near Coeur d'Alene, Idaho, on *P. contorta*. Sparingly distributed throughout the Northwest are some large forms of *Razoumofskya* on *Abies*. Plants collected by the writer on *Abies grandis* and *A. concolor* are apparently the same as that described by Engelmann (3, v. 2, p. 106) on the former host under the name *Arceuthobium occidentale* var. *abietinum*. Although it would probably be better on morphological grounds to refer this form to *R. campylopoda* (Engelm.) Piper, as Engelmann's *Arceuthobium occidentale* is now named, owing to its seeming close affinity to the genus *Abies* and the absence of cross-inoculation data it could well be raised to specific rank. These mistletoes in point of morphology are in great contrast with the small forms on *Abies* previously mentioned. They may be considered typical of a group of large forms occurring only on *Abies*.

From the foregoing, it seems possible that the members of the genus *Razoumofskya* may be arranged in a series of natural groups according to their host relationships. It is also interesting to note that the largest, the longest lived (both cortical and aerial parts), and the most strictly parasitic forms are associated with the hard or yellow pines. These pines exhibit anatomically a high differentiation. This may throw some light on the nutrient relation of some mistletoes to their hosts; also their family peculiarities.

SUGGESTIONS FOR CONTROL.

It is clear from the foregoing pages that the damage to forest growth by the mistletoes of coniferous trees in the Northwest is of sufficient importance to receive the attention of every forester. Steps should be taken in all logging operations, where local problems of economy do not interfere, to make a beginning of the eradication of mistletoe by marking every infected tree for cutting. In some cases it would seem advisable to introduce into the contract a special clause dealing wholly with mistletoe-infected trees. The most injurious of the mistletoes of the genus *Razoumofskya* on coniferous trees, as indicated, are in the main confined to their own particular hosts or to special groups; hence, it is not advisable to establish in mistletoe regions pure stands of a species much subject to attack. In this respect the problem of the control of mistletoe is similar to that of forest-tree fungi. Mistletoes being light-loving plants, close stands should be maintained as much as possible on all exposed parts of the forest. For the same reason rims of canyons and all exposed areas, such as the borders of bench lands, natural parks, shores of lakes, etc., should be protected with species which are not usually subject to the ravages

of mistletoes (Pl. IV, fig. 2). In this class would fall the firs, spruces, arbor vitæ, cedars, junipers, and yews. If this can not be done, owing to certain requirements by these species on soil and climate, the stand should be composed of as many different species as possible.

Aside from reasons already set forth, isolated seed trees heavily or even slightly infected by mistletoe should not be retained. The vigor of the parasite on the parent tree will become greater, owing to its response to open and well-lighted conditions. Reproduction under the tree and in its near vicinity, if of the same species, will readily become infected. The same will be true of seed plats. The force developed within the mature seed capsule of these mistletoes and exerted in the expulsion of the seed is a factor of great significance for the spread of the parasite. It has been demonstrated in the case of one species that this force is sufficient, starting at an elevation of 8 feet on the level, to carry the seed a distance of over 66 feet. In addition to the forcible expulsion of its seeds by the parasite, strong wind is an important factor in seed dissemination. In one instance seeds of the larch mistletoe were collected in number from the roof of a cabin one-fourth of a mile away from the nearest infected tree. This is not at all extraordinary, in view of the fact that the larches of the region are very tall and are heavily infected in the crown. Also strong winds are frequent during the period of seed maturity. Birds and animals play a minor rôle in the distribution of the seeds of these mistletoes.¹ In the present instance, however, the seeds adhered to the substratum in the usual and normal manner and could not have been transported in such numbers by any other means than strong wind.

In view of the fact that strong air currents are factors in the dissemination of the seeds, some consideration should be given to the topography and prevailing winds of a region where mistletoe abounds, as influencing the selection of seed plats (if such methods are employed), the placing of strip cuttings, and even of nursery and transplant beds. On a previous page, the tender age at which coniferous seedlings are liable to infection by mistletoe is indicated, so that the above statement regarding nursery sites is not merely a conjecture. Since considerable time elapses between the actual penetration of the primary sinker and the time the infection becomes conspicuous, three years in some instances, it is quite possible for

¹ In Bulletin 317 of the U. S. Department of Agriculture, page 24, the writer published a footnote on the rôle of birds and animals in the distribution of the seeds of these mistletoes. Since this publication was issued additional observations show that the seeds are probably more widely distributed by this means than was formerly believed. A rumor has been long extant that grouse feed upon the mistletoes. This has recently been verified by the writer by finding in the crop of a grouse the mature seeds and plants of the Douglas fir and larch mistletoes. Mr. Donald Morrison, an old, experienced hunter residing in the mountains near Missoula, states that grouse in the late fall, with the coming of the winter snows, make a practice of congregating in the dense houselike brooms of the Douglas fir mistletoe. Mr. Morrison states quite positively that these birds feed upon the plants and mature seeds of these parasites when other forms of food become scarce.

young infections on nursery stock to escape detection. Accordingly, young infected seedlings may become a means of distributing and establishing the parasite in plantations generally, not only locally but to far distant regions, when growing stock is shipped either for experimental purposes or for permanent plantings. That this is possible is shown by the discovery in the planting areas near Wallace, Idaho (Coeur d'Alene National Forest), of a yellow-pine seedling showing a very recent infection of mistletoe. Since the plantings were made on a widely denuded area and no yellow-pine mistletoe is as yet known to occur in the immediate region, it seems that the seedling must have become infected while at the home nursery at Boulder, Mont., where this mistletoe occurs. In view of the fact that there is a very grave danger of transporting agents injurious to forest growth, either fungous diseases or mistletoe, by sending nursery stock to distant parts of the country, the need of strict sanitation in the neighborhood of forest-tree nurseries can not be overemphasized. Whenever new nursery sites are planned in or near forests, a close pathological survey should be made of the surroundings, and trees diseased or suppressed from any cause whatever should be cut out. This should be done also where nurseries are already established.

The influence of the physical type on the severity of attack should receive considerable attention in any plan of management of forests in mistletoe regions. Forest Assistant Gilkey, in a report on the western larch of the Whitman National Forest, states that "a total of several hundred trees in various parts of the forest shows 79 per cent of the larch to be attacked on the dry-slope type, with only 27 per cent on the more moist sites." The writer's own investigation in the same forest shows an even greater difference between the moist-valley type and the more exposed slopes, which was 87 per cent for the latter and 15 per cent for the former. The severity of the infection on yellow pine and Douglas fir in other regions likewise shows wide extremes as influenced by elevation and exposure. Mr. E. E. Hubert, of the Laboratory of Forest Pathology, reports from extensive observations during a reconnoissance of the lodgepole pine in the Big Hole Valley, Mont., that the most favorable sites for mistletoe are exposed dry ridges and south slopes, where the infection ranges from 50 to 70 per cent of the stand. In the valley type the percentage of infection was much lower.

In view of the fact that all economic species so far observed are subject to attack at any age, it is hardly possible to establish an age at which infection becomes so serious as to interfere with the merchantability of the host. In regions of heavy mistletoe infection it would be quite impossible, for the reason that there is a much greater chance for all age classes to become infected. In numerous in-

stances, however, it is noted that in some regions Douglas fir, larch, and lodgepole pine first become conspicuously infected at sapling or pole size; that is, it has required several years for earlier infections to become prominent. In any case, the matter turns on the time of life at which a tree becomes infected. If seriously infected before pole size is reached, the whole tree will in all probability be a cull and a menace to the forest. If infected during or after pole age, the tree may furnish some merchantable material, but will mature far in advance of uninfected trees of the region. Trees infected during early maturity may not be seriously influenced by the parasite except that their life functions may be slightly changed by brooming and breakage of branches, thus hastening the period of decline. Cutting old and suppressed mistletoe trees is, of course, a saving in several ways, not only to the future forest, but it is getting the best out of a rapidly declining forest capital. Their destruction, however, does not mean that a great advance is being made in eradicating the mistletoe from the region. It simply lessens the chance of infection for a time. Cutting the old and merchantable infected trees and leaving the younger unmerchantable but infected growth will not answer the purpose of control in regions of heavy infection. Very frequently the removal of only the more merchantable mistletoe trees causes the parasite on the trees that are left to develop more vigorously. Numerous observations show that infected trees of various ages succumb very rapidly to the parasite after a certain percentage of the stand has been cut out. For this reason marking the most seriously infected trees for cutting, with the prospect of the least infected reaching a normal maturity or a state of high merchantability, should in many regions be discontinued. The only plan left, then, in many regional units of infection is to practice heavier marking than hitherto employed, or, better still, clean cutting. It is believed that a close survey of the forests of each district will result in the discovery that there are units or centers of great infection either for one species of mistletoe or for different species.

Instances of great regional infection for the Northwest have already been indicated. Strange to say, in some cases these centers of infection are quite sharply defined. It seems entirely possible that if these regions were carefully studied and mapped as to the possible environmental factors governing the vertical and horizontal distribution of the parasite, much practical knowledge would result. If the region should be accessible, the sales policy could be modified, with strong emphasis on the control of the mistletoe, and the knowledge already gained from a detailed study of the region should be available for future forest management. It must be remembered that the great injury now exhibited by forest growth is the accumulation of many years of unhindered activity by these

mistletoes. Through a proper appreciation of the need of adopting control measures in all sales areas where the percentage of infection is high and in all replanting projects in mistletoe regions, with the free-use privileges of mistletoed trees and the cutting of all infected growth in the vicinity of forest-improvement stations, a good beginning could be made toward the eradication or the lessening of the ravages of these parasites.

SUMMARY.

The conifers in the Northwest most subject to injury by mistletoes of the genus *Razoumofskya* are *Larix occidentalis*, *Pinus contorta*, *Pseudotsuga taxifolia*, and *Pinus ponderosa*. In the order of the above-named hosts the mistletoes most responsible for the greatest damage are *Razoumofskya laricis*, *R. americana*, *R. douglasii*, and *R. campylopoda*.

The general nature of the injury by these mistletoes is expressed in a gradual reduction of the leaf surface of the host, which causes a great reduction of growth in height and diameter.

New infections take place only through the agency of a germinating seed, which reaches the point of infection through the natural expelling force of the seed capsule, which may be made more effective in point of distance traveled by the aid of strong winds, by falling from branches above after they have been loosened from their original resting place by rains, and by animal life.

Trees of all age classes are liable to infection provided the mistletoe seeds fall on parts of the host not yet protected by the mature cortex. The parasite may spread from the original point of infection into older cortical tissues, which are not liable to infection from without. The spread of the cortical stroma in the reverse direction from the line of growth of the branch may continue until the outer cortex becomes too thick for the aerial shoots to penetrate it. After this, the cortical roots become suppressed and eventually die, or they may become wholly parasitic.

Excessive mistletoe infection of the lower branches of a tree may cause the upper portion of the crown to die, giving rise to the phenomenon commonly called staghead or spiketop. Severe infection throughout the entire crown often results in the death of the tree. Young seedlings from 3 to 6 years old are often killed within a comparatively short time after infection.

Infection on the branches in practically all cases causes the formation of large brooms, which seriously interfere with the life function of the tree. The same is true in the case of infection on the trunk, whereby burls are formed.

The weakening effect of the formation of burls and brooms by mistletoe on forest trees is often responsible for serious depredations by fungi and forest-tree insects.

In point of quality and quantity the seed-producing capacity of trees suppressed by mistletoe is far below that of normal uninfected trees.

Mistletoe can be controlled. It is suggested that a beginning may be made in its eradication or in the reduction of the ravages caused by these parasites by working along the lines indicated in the last section of this bulletin.

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WM. A. TAYLOR, Chief



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PROFESSIONAL PAPER.

April 7, 1916

FOREST PATHOLOGY IN FOREST REGULATION.

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INTRODUCTION.

At the time of the creation of the national forests in the United States the Government very suddenly found itself confronted with the problem of organizing an enormous acreage of practically virgin timber. It was natural that American forestry turned to the experience of the Old World for guidance in this huge task; it was quite as natural that the present state of European forestry should have served as the ideal to be reached in the shortest time possible. In organizing the administrative machinery, European precedent could be followed more or less closely, but not so in almost all other phases of forestry. Except for certain economic factors and the development of modern machinery, conditions influencing the lumber industry in the United States are very dissimilar to those in the typical forest countries of central Europe. Our virgin forests them-

NOTE.—This bulletin discusses the bearing of modern forest pathology on forest regulation.

selves, and consequently the timber for sale, are more or less in the condition of European forests of several hundred years ago. The administration found itself then in the position of a man forced to take over not only an obsolete factory producing at random articles of daily necessity in enormous quantities without having any control whatever over the quality turned out, but also a huge stock of products of all kinds and all values. Modern sales methods alone can not make the product any better, and the sudden adoption of modern methods of efficiency in the manufacturing end of the business would soon disorganize the entire factory.

It is clear that in the most important branch of forestry, silviculture, the blind adoption of European methods must encounter serious difficulties. Perhaps we are too prone to look upon European forestry as a science worked out in all its details, the results of which are universally accepted as definitely settled. Critical perusal of modern European forestry literature shows an entirely different state of affairs. Even in Germany many of the fundamental problems of forest organization are steadily discussed and are far from being considered as settled. Furthermore, what Gaskill¹ said 11 years ago is true to-day, namely, that "European foresters have not developed a true system or science of silviculture capable of being applied to virgin conditions or to all conditions."

The lessons taught us by earlier forest history in Europe, the adaptation rather than adoption of European principles to American conditions, and the development of new principles to suit our own special needs are therefore the means by which forestry in the United States will finally solve the silvicultural problems before it at the present day.

REGULATION OF YIELD.

WORKING PLANS.

One fundamental problem has occupied the administration of the national forests ever since their creation, that of working plans as the expression of forest organization leading to sustained yield.

Any speculation with regard to the adoption of a system of regulation must necessarily refer to the normal stand, whether this is clearly understood and stated or not. Now, there is no such thing as the 100 per cent normal stand. Consciously or subconsciously the normal stand is taken as the ideal, and from this allowances are made according to the degree in which the stand deviates from the normal. It is a remarkable fact that even in European forestry no working system has developed of expressing with accuracy the value of allowances to be made. This is partly due to the fact that the managed European forests are relatively closer to the normal. Frequent thinnings and improvement fellings eliminate most of the undesirable indi-

¹ Gaskill, Alfred. Silviculture applied to virgin forest conditions. *In* Proc. Soc. Amer. Forest., v. 1, no. 2, pp. 62-69, 1905. (See p. 67.)

viduals from the stand, which is kept as fully stocked as possible. The problem is further simplified by the prevalence of pure stands or of stands composed of two, rarely more, well-matched species. The management of even-aged stands or stands of all ages also permits a relatively close approximation to the normal.

All these factors are comparatively rare in our practically virgin forests, which are about as far from the normal as possible. As forests they are with few exceptions rather 100 per cent abnormal, and this applies equally well to all unmanaged practically and genuinely virgin forests of the world. The farther the forests are removed from the normal the less can European results from relatively normal stands be applied, and particularly if the abnormality is complicated by the presence of a greater number of commercial species on the same stand, as is so often the case in our forests. It is not to be expected that at the very beginning of its career the Forest Service should have possessed all the facts upon which to base a rational system of sustained yield. Intensive work of decades is necessary to secure even the very foundations.

It is clear that this lack of fundamental facts must be reflected in any attempt to establish some system of sustained yield and, therefore, in any policy of regulation of cut. While Kirkland¹ emphatically demands a policy of cutting national-forest timber on the Pacific coast on the basis of a sustained annual yield, Greeley,² on the other hand, points to the difficulties confronting the establishment of a sustained annual yield in the forests of the United States. In his opinion even, "modern conditions governing the distribution and sale of lumber make the sustained yield from the standpoint of a permanent supply for consumers of wood very much of a fiction." We have at the present time no more authoritative statement concerning the policy of the administration of the national forests.

With regard to the regulation of sustained yield, Chapman³ arrives at a similar result in discussing the regulation of cut on national forests.

Until recently the annual cut permitted upon national forests has been determined by Von Mantel's method, based solely on the present nature of the merchantable stand and a somewhat arbitrary rotation. A few attempts have been made lately to base the cut upon the increment of the forest by use of the Austrian formula. At the same time there has come a general awakening to the fact that our knowledge of the actual increment of virgin forests is conspicuously lacking. Without this knowledge systematic regulation of yield must remain on crude and wholly unsatisfactory foundations. The question can not be dodged by quoting the generality that in virgin forests growth equals decay.

¹ Kirkland, B. P. The need of a vigorous policy of encouraging cutting on the national forests of the Pacific coast. *In* Forestry Quart., v. 9, no. 3, pp. 375-390, 1911.

² Greeley, W. B. National forest sales on the Pacific coast. *In* Proc. Soc. Amer. Forest., v. 7, no. 1, pp. 42-50, 1912.

³ Chapman, H. H. Coordination of growth studies, reconnaissance and regulation of yield on national forests. *In* Proc. Soc. Amer. Forest., v. 8, no. 3, pp. 317-326, 1913.

This "generality," in which almost every word is open to criticism, seems to have become one of the stand-bys of American forestry. It finds its chief support in the assumption that our forests to-day, having been untouched by man and exposed to the same factors of their surroundings since times immemorial, must represent more or less exactly the same character they had 100 or 1,000 years ago. But we have practically no genuinely virgin forests; in the great majority of commercial accessible stands—and here we are interested only in these—man has for centuries practiced some kind of primitive forestry by setting fires. This "Piute forestry" has changed the aspect of many stands so completely that the term "virgin forests" is far from being correctly applied. At best, can one speak of scattered virgin stands here and there. Even in the latter the assumption that the present stand has more or less the same character as 100 to 1,000 years ago reposes upon another assumption, namely, that here the ecological formation has reached the final stage of development and has come to stay. Of the remaining part of the cited rule of thumb all factors are more or less unknown.

Our knowledge of increment is, according to Chapman, "conspicuously lacking."¹ We know just as little about actual extent and progress of decay in virgin forests, so that the "generality" is reduced to an equation in which all factors are unknown. Besides, the term "decay" leaves out all losses from the decrease in number of trees steadily going on in the forest, as in every community of living beings. Prompted, perhaps, by a subconscious realization of this fact, the term "decay" in the equation is sometimes supplanted by "deterioration." This makes matters even worse. Deterioration in this connection often means the visible loss irrespective of cause. It is primarily a numerical consideration. A number of trees containing certain amounts of timber annually drop out through various causes, and this loss is then said to offset the annual increment. Secondly, it might include loss from decay. In forest regulation it is not the number of trees and the volume of timber they produce per acre that count, but the volume of sound, merchantable timber that we can expect to raise; and the only factor in the equation of any value would be, therefore, not decay only and deterioration or numerical loss of individual trees but "total loss." The components of this total-loss factor are known. They include the dropping out of individual trees by death from suppression or "old age," fire, snowbreak, lightning, windfall, insects, diseases of vital parts of the tree, and finally loss through decay. What we do not know are the respective values to substitute for these components in the actual figuring of total loss.

¹ More recently Barrington Moore has published a valuable study—Yield in uneven-aged stands—in *Proc. Soc. Amer. Forest.*, v. 9, no. 2, pp. 216-228, 1914.

The same laxity noted in the use of the terms "decay" and "deterioration" is commonly found in the use of the term "decadence," as applied to a stand or a given species, which is often understood to include individual decadence from old age; that is, arrested or minimized growth, liability to attack from fungi and insects, and finally decay. The fact that a given species is unusually liable to heart rot does not make it decadent. Many of our most thrifty and aggressive species are particularly subject to heart rot. It is also doubtful whether this hypothetical knowledge, if ever attained, of the total rate of total loss in "virgin" forests, as compared with the equally hypothetical rate of increment of the forests as a whole, would help us to any extent. The vastness of our forests in area creates a tendency either to think in broadest terms and to overlook the fact that a forest is an artificial unit made up of natural units, the stands with all their immense variety of character, or, on the other side, to take a familiar unit and to transfer its characteristics to the whole. The latter mistake is more easily remedied than the first. As a science, forestry must be founded upon inductive methods. Intensive study of detail alone can form a solid basis for the formulation of principles.

What is needed is exact studies of all components of the total-loss factor per species before we attempt to fix the total-loss factor for the stand.

Such detailed studies will be easiest in all-aged pure stands of a thrifty species little liable to decay. Unfortunately the vast majority of stands on national forests in the West are composed of two to five or more species of very different characters. It may be that the total annual loss equals the annual increment in some of the medium long-lived species of the pine group least liable to decay. It can not be true for the extraordinarily long-lived redwood and big tree, with their unusual resistance to decay, insects, and storms. It is equally untrue for all shorter lived species much exposed to decay and other influences that make for loss. *Libocedrus decurrens*, for example, although most aggressive and thrifty, is from an early age on liable in an uncommon degree to the attacks of *Polyporus amarus*, which renders as much as 70 or 80 per cent and even higher percentages of the stand completely unmerchantable. Merchantable incense cedar is of high value; so much the greater, then, is the total-loss factor. The same is, *mutatis mutandis*, true for white fir and a number of other species. For all these the increment is not only offset but far exceeded by the decay of the valuable heartwood; the total annual loss is far greater than the annual increment, although numerically the loss may not be apparent.

The gain through increment, we must remember, consists of sapwood of little value; the loss by decay, on the other side, affects the

valuable heartwood. Neither is there any constant accumulation of gain; after some years the sapwood is turned into heartwood and as such becomes liable to decay. In other words, in trees of this group infected with heartwood-destroying fungi, the value of newly formed wood is small; when it becomes valuable by transformation into heartwood it becomes subject to decay—that is, loss. This loss from decay is by its very nature as a heart rot confined to those individuals in which heart-rot formation has taken place. All trees below the age of heartwood formation do not enter into consideration. In speaking of a given stand the representation by ages must be of prime importance. In all considerations of regulation it is necessary, therefore, to make a clear distinction between forests and stands, between many-aged and even-aged stands, between mixed and pure stands, with particular emphasis on the composition of the stand as to species. All generalization is not only useless but misleading.

But in full realization of the almost complete lack of fundamental knowledge, American forestry is confronted with the urgent necessity of adopting, even temporarily, some kind of a system of regulation of yield. Whatever this system may be, its tentative, temporary, and local character can not be overemphasized.

Various attempts at adopting local temporary systems have found an expression in the shape of working plans. Inseparable from the problem of working plans is the choice of a rational rotation and cutting cycle.

ROTATION.

The gleanings in American literature treating on the choice of rotation from a general point of view are rather meager, outside of a few well-known handbooks, such as those by Recknagel,¹ by Fernow,² and by Roth,³ particularly in so far as the practical application to our virgin forests is concerned. Recknagel⁴ excludes financial rotation from North American forests with the following words:

Since this method of calculating the rotation [financial rotation or that of highest soil rent] is suitable only to very intensive conditions, it would serve no useful purpose to elaborate it at this point.

On the other hand, the strong influence of European forestry is clearly felt in the ever-recurring advice to adopt some kind of a financial rotation in the national forests of the United States. Kirkland⁵ is of the opinion that—

¹ Recknagel, A. B. *The Theory and Practice of Working Plans (Forest Organization)*, 235 pp. New York, 1913.

² Fernow, B. E. *Economics of Forestry*, 520 pp. New York, 1902.

³ Roth, Filibert. *Forest Regulation, or the Preparation and Development of Forest Working Plans*, 218 pp., illus. (maps). Ann Arbor, Mich., 1914. (*His Michigan Manual of Forestry*, v. 1.)

⁴ Recknagel, A. B. *Op. cit.*, p. 39.

⁵ Kirkland, B. P. Working plans for national forests of the Pacific Northwest. *In Proc. Soc. Amer. Forest.*, v. 6, no. 1, pp. 16-37, 1911. (See p. 21.)

A rotation based on the financial rotation, possibly modified somewhat towards the rotation of the highest income, is no less adapted to Government forestry than to private forestry.

Greenamyre¹ advocates a financial rotation in the composite type of the Apache National Forest, the "rotation of greatest volume production being out of question." In his specific recommendations for western yellow pine, Douglas fir, and blue spruce, however, rotation of greatest volume plays a far greater rôle than financial rotation. Such important factors in financial rotation as soil capital, quality increment, and rent are neglected or only hinted at. Value increment and depreciation enter into his calculations in a general way only, evidently from a lack of exact figures.

Barrington Moore² expresses himself strongly against the adoption of a financial rotation.

It would be out of place in this paper to enter into a discussion of the possibility at the present time of fixing a rotation of greatest income or a financial rotation more deeply than to point to the immense difficulties encountered as soon as we try to substitute actual values for the factors entering into their computation derived from experience in our own country. We lack at the present time the very fundamentals on which to base the determination of highest forest rent or highest soil rent.

The Forest Service has, in full realization of the uncertainty of almost all factors which would or should enter into a financial rotation formula, adopted, for the present at least, a tentative silvicultural rotation of maximum-volume production.

The factors entering into the determination of silvicultural rotation or of greatest volume being more easily accessible, it is quite natural that American forestry should show a tendency toward its application, as shown in a number of published and unpublished working plans.

Attempts at fixing some kind of a rotation age are found in several publications. Woolsey³ tentatively proposes a rotation of 200 years for yellow pine without giving a basis for the choice of any particular system of rotation.

Barrington Moore⁴ says that on the Plumas National Forest "the rotation should theoretically be that of maximum-volume production. The use of a financial rotation by the Government, in a region

¹ Greenamyre, H. H. The composite type on the Apache National Forest. U. S. Dept. Agr., Forest Serv. Bul. 125, 32 pp., 4 figs., 1913. (See p. 30.)

² Moore, Barrington. The essentials in working plans for national forests. In Proc. Soc. Amer. Forest., v. 6, no. 2, pp. 117-128, 1911. (See p. 126.)

³ Woolsey, T. S. Western yellow pine in Arizona and New Mexico. U. S. Dept. Agr., Forest Serv. Bul. 101, 64 pp., 11 figs., 4 pls., 1911. (See p. 51.)

⁴ Moore, Barrington. Chapman's method of studying yield, p. 93, 1913. To accompany forest plan, Plumas National Forest, district 5. Appendix (continued), Silviculture. (Unpublished. Furnished by courtesy of the U. S. Forest Service.)

capable of producing large saw timber, can not be justified. * * * It would probably be better to fix the rotation at the period during which the *rate* of volume production is greatest or shortly after it, provided this is long enough to give the most valuable product."

Munger¹ comes somewhat closer to a consideration of the financial factors for a rotation of Douglas fir in pure even-aged stands in the Pacific Northwest.

From the quotations given, one fact stands out clearly: We are still groping more or less in the dark where choice of rotation is concerned, and we are even lacking the fundamentals upon which to base the principles to govern us in making a proper choice. It also appears that in many cases the term "actual felling age" should be substituted for rotation. Rotation in itself signifies return or succession in a series. Fernow² has warned, as early as 1905, against mixing up "actual felling age, the time when a stand is actually cut or to be cut, and normal felling age (rotation), the time when in a scheme of continued management it is proposed to have it cut again and again—a mere standard time. Few stands are cut in the age of the rotation determined for the forest as a whole." Where a "rotation" of yellow pine, for instance, of 200 years is advocated, it is evident that this can not be meant to constitute the fixed period at which yellow pine should be cut again and again in the future. It is really the actual felling age, the time when a given stand of yellow pine is actually to be cut in the future, not a succession of 200-year periods. The rotation itself will be much shorter, as European experience has shown us. Moreover, it is more than doubtful whether our successors in 200 to 400 years will pay much attention to the rules we may try to lay down for so remote a future.

CUTTING CYCLE.

The impossibility of predicting with even a modest degree of probability what will happen in the future and of anticipating changes in conditions of an economic nature is responsible for the vagueness with which the question of fixing definite cutting cycles is treated. Tentatively, cutting cycles of about 50 years have repeatedly been advocated for uneven-aged stands (mixed and pure) under the selection method, as a policy to be followed on virgin national forests. If present economic conditions should prevail in the next 50 years—that is, if the demand for timber should continue to fall far short of the actual annual increment—it would hardly pay a lumbering concern of the future to extend its operations to cut-over areas before 50 to 60 years had elapsed. Even then it seems doubtful whether the

¹ Munger, T. T. The growth and management of Douglas fir in the Pacific northwest. U.S. Dept. Agr., Forest Serv. Circ. 175, 27 pp., 4 figs., 1911.

² Fernow, B. E. Forest terminology. In *Forestry Quart.*, v. 3, no. 3, pp. 255-268, 1905. (See p. 264.)

amount of timber contained in the few overholders left as seed trees and in individuals at or just below the diameter limit established in a first cutting would prove attractive to purchasers of the future, provided always no change in the lumber market should take place. The diameter limit now fixed on many national forests may be said to be about 12 inches, varying somewhat with the species and local conditions. Few trees below this diameter will reach such dimensions in 50 years as to form a merchantable stand, judged by our standards of to-day.

If it is unwise blindly to take over principles and policies developed and more or less accepted in countries with old-established and far-advanced forestry and apply them to the first stages in the organization of our virgin forests, the study of the history of the forestry movement and development in other countries can not but be of the greatest practical value. We are justified also in assuming that the history of forestry will repeat itself and that forestry in all countries with large virgin or practically virgin forests in touch with the general market will run through the same phases of development as it did during the last centuries in central Europe, but at a very much faster pace, owing to the enormously enhanced facilities of transportation and marketing and the rapidly increasing demand for timber.

If this be true, a cutting cycle of about 50 years may prove too long. To judge from the development of timber values in Europe, our once cut-over stands should prove attractive in a shorter period.

In determining the duration of cutting cycles, it is reasoned that the accessible virgin timber in the national forests should be cut once before operations return to the first areas logged over. How much time this first culling may consume we have no means of telling. It should be remembered, however, that the system naturally presenting itself is that of selection cutting, and although there is a decided tendency toward heavier marking approaching clean cutting, this latter should be taken *cum grano salis*. Actually, the reproduction left includes all individuals up to and sometimes beyond 12 inches diameter breast high; that is, trees that have reached a considerable age and that in 50 years will have grown to what would be classed in European forestry as veterans.

CUMULATIVE RISK.

In fixing long-term cutting cycles, a most important point has not been sufficiently emphasized, namely, the "cumulative risk" from fire, windfall, frost, and so-called deterioration to which a given stand is exposed during so long a period. The longer the cycle the greater the ratio of risk. The unparalleled development of fire protection in the national forests of the United States, it is true, promises fairly to exclude actual destruction from fire on any large scale; but, as long as

there will be fires from unpreventable sources (lightning), the risk in extended cutting cycles increases from year to year with the growth in value of the stand. The shorter the period in which a merchantable stand can be produced and turned into cash the smaller will be the risk of loss.

Loss from windfall is inevitable in many localities as a direct consequence of selection cutting. It is clear that the cumulative risk of a longer cycle is far in excess of a shorter one. Evidently, devastating windstorms are more likely to occur during a period of 50 years than during a shorter one. Moreover, the loss in cash value, even in single trees, from windfall is bound to be heavier in the older stands. The larger, bulkier, and therefore the more valuable the tree, if sound, the more it is exposed to windfall. Falling trees in brushing against their standing neighbors not infrequently cause more or less serious wounds by bruising or tearing off the bark.

The greatest risk, however, involved in the long cutting period is from "deterioration," so called.

In nature a steady process of elimination goes on. Of thousands of seedlings springing up together in dense growths, comparatively few reach sapling size, very few grow into poles, and fewer, even, to standards. This natural thinning through competition in the fight for soil, food, and light is furthered by various dangers to which the young plants are exposed, such as from certain insects, foliage and twig diseases, injury from mammals, snowbreak, frost, and drought. Later, the surviving members of the stand are confronted with dangers from the same and other sources, such as suppression, lightning, insects, frost, and decay. The elimination of the weaker members effects a selection of older, well-established individuals, some of which may still suffer from the competition of their thriftier neighbors, but are not forced out of the community, or, to use Fernow's¹ well-chosen terminology, trees which are "oppressed," not suppressed. As long as improvement cutting on a larger scale on the national forests is impossible, the percentage of oppressed trees will depend upon the length of the cutting cycle. Both these oppressed trees and their more favored companions are exposed to dangers from which their earlier life was free.

Frost does a good deal of damage; here we are less interested in the damage done to the foliage or to the bark than in those more or less long cracks in the wood which are caused by very low temperatures. In cold weather the wood cylinder shrinks more in a tangential than in a radial direction. Particularly at sudden low temperatures, when the volume of the outer layers decreases rather suddenly while the inner layers are still free from frost and have

¹ Fernow, B. E. Forest terminology. In *Forestry Quart.*, v. 3, no. 3, pp. 255-268, 1905. (See p. 266.)

shrunk but little, differences in internal tension will cause the outer layers to split vertically. With rising temperature the frost crack closes. Not always is the bark able to stretch sufficiently over a frost crack. Often the bark tears open, and if low temperature occurs again and again, the cracks will not be able to heal over and will remain open for many years, giving the air access to the heartwood and incidentally allowing spores of wood-destroying fungi to germinate and infect it. Even if no infection takes place, these frost cracks very seriously impair the value of the timber. The older and bulkier the tree the greater is the danger of frost-crack formation. The risk naturally increases with the length of the cutting cycle. Infection, of course, can take place only through open frost cracks; internal frost cracks, besides impairing the value of the timber, can not be without influence on the chemistry and physics of the wood.

Although lightning occasionally strikes the smaller trees, even poles and saplings, it is to be expected in the nature of things that taller trees will be more exposed to injury from this cause. Very little is known, so far, as to the actual damage done by lightning in our forests. Destruction of individual trees has been frequently reported, and Plummer¹ gives a series of illustrations of injury to forest trees from lightning. He treats, however, only of those very gross cases in which even the least educated eye will recognize the cause of the injury.

We know through Robert Hartig's² classical investigations, which were continued by Von Tubeuf, that destructive lightning is rare in comparison to the overwhelmingly greater number of cases of lighter injury from lightning, varying from more or less large wounds visible on the outside of the tree to the small and insignificant local killing of parts of the cambium and of the living bark which can only be detected by careful dissecting.

The symptoms of lightning injury in our forest trees are easily recognized from Hartig's excellent descriptions. They are particularly common and conspicuous in white fir.

For practical purposes, we have to consider here only those forms of lightning injury which in some way endanger the life, the health, or the commercial value of the tree; this will include not only actually destructive cases, but also very large numbers of lesser injuries. The accumulation of risk during a long-time cutting cycle becomes self-evident, particularly in view of the fact that the danger from lightning increases quite out of proportion to the increase in height of the tree and the development of the root system.

¹ Plummer, F. G. Lightning in relation to forest fires. U. S. Dept. Agr., Forest Serv. Bul. 111, 39 pp., 16 figs., 1912.

² Hartig, Robert. Untersuchungen über Blitzschläge in Waldbäumen. In *Forstl. Naturw. Ztschr.*, Jahrg. 6, 1897, Heft 3, pp. 97-120; Heft 4, pp. 145-165; Heft 5, pp. 193-206. 83 figs.

Hartig, Robert. Neue Beobachtungen über Blitzbeschädigung der Bäume. In *Centrbl. Gesam. Forstw.*, Jahrg. 25, 1899, Heft 8-9, pp. 360-381, figs. 47-71; Heft 12, pp. 523-544, figs. 81-110.

Although young trees are also exposed to the attack of insects, it is clear that a colony of bark beetles will prove far more injurious in killing a merchantable tree than in killing a small pole. Moreover, certain insects seem to have a predilection for larger sizes. The probabilities of attack increase with the length of the cutting cycle. Besides, the older the tree and the more it has been exposed to wounding the more liable does it become to attack by wood-boring insects which materially reduce the value of the timber.

The timber contained in trees killed by lightning, as long as they are not destroyed, and in those killed by bark beetles may be utilized, and, with increasing timber values, will be utilized before they deteriorate.

The few veterans which have withstood the many dangers of earlier life do not go on living forever; they finally succumb like the rest.

It is still an open question whether forest trees are theoretically immortal and die only through the devastating influence of severe storms, lightning, insects, certain diseases caused by fungi, such as *Armillaria mellea* and *Fomes annosus*, or because the root system of the veteran finally has exhausted all available resources of the soil within its reach. As we are interested here only in the future of cut-over areas in relation to the length of the cutting cycle, it is unnecessary to enter into a discussion of this question. The cutting cycle for any one species will in all probability never be long enough to raise individual decadence from old age to the rank of an influencing factor. We should bear in mind, however, that individual decadence is not in itself deterioration unless decay sets in.

The importance of the reduction in the timber value of the tree through the agency of fungi, on the other side, can not be overemphasized. This reduction in timber affects either the prospective timber values—that is, the increment—or the present stock, or both. In the first case, the fungi in question (mostly *Pyrenomycetes* and rust fungi) inhabit living tissues of the foliage or of the young bark. The continuous drain on the assimilates of the foliage either in the leaves proper or on their way down through the bark is evidenced by a decrease in increment of the tree, which in long cutting cycles will represent a very considerable loss in timber values. In other words, trees affected with foliage or bark diseases will be far from yielding the timber we might expect from sound trees. It must be mentioned that losses in prospective values are not alone due to fungi; mistletoes and leaf-inhabiting insects are responsible for enormous deficits in yield. The economic rôle of the fungi, mistletoes, and leaf-inhabiting insects in our virgin forests is highly important and will remain so for a long time, on account of the difficulties connected with their control and even more on account of our very limited knowledge concerning their life histories and specific action. More intensive studies

on the members of this group must be left to the future. At the present time we are more interested in the preservation of our actual timber, including such values as will be formed in the near future.

Actual timber values are seriously endangered by wood-destroying fungi, all of which belong to the Hymenomycetes. With the exception of a very few (*Armillaria mellea*, *Pomes annosus*), which in attacking living roots first cut down the increment of their host and then invade the wood of the bole, they all inhabit the heartwood and generally leave the sapwood intact. As the principal timber values are stored in the heartwood, the enormous damage they are able to cause is all the more in evidence. All of these fungi are adapted to given hosts or groups of hosts; these groups are seldom very large. *Polyporus amarus*, for example, the cause of the extremely destructive heart rot of *Libocedrus decurrens*, can not grow, as far as is known, in any other host species. *Trametes pini*, on the other hand, attacks a number of pines, Douglas fir, and other conifers. The composition of the stand, as well as the representation of species, is therefore an important factor in the ecology of these fungi. Only those fungous spores which land on trees of the species to which they are adapted have a chance after germination to enter into the tree.

Being strictly heartwood inhabiting, these fungi, with the exceptions mentioned above, can, of course, only attack trees which already have formed heartwood. But as they are unable to penetrate the bark, they are harmless unless their spores are carried on to some wound or opening (branch stubs) in the protective skin represented by the bark. The longer the host is exposed to wounding, the greater will be the chances for infection.

As might be expected, therefore, the losses from decay in standing living trees are enormous in virgin forests. Even in the best managed forests of Germany losses from decay are heavy. Möller,¹ in figuring the damage done by *Trametes pini* in the pine forests of the Prussian Government, arrives at the astounding figure of more than 1 million marks (about \$250,000) annual loss from this source alone. In the period from 1905 to 1908 the Prussian Government spent \$87,480 in the control of *Trametes pini* in its pine forests.² In 1914 this sum had increased to about \$120,000.³

In American literature no reliable figures are available relating to the annual loss from decay in standing timber in virgin forests. Such figures can be obtained only by exact studies on representative areas, the methods of which the writer has been trying to work out

¹ Möller, A. Über die Notwendigkeit und Möglichkeit wirksamer Bekämpfung des Kiefernbaumschwammes *Trametes pini* (Thore) Fries. In Ztschr. Forst- u. Jagdw., Jahrg. 36, 1904, Heft 11, pp. 677-715, pls. 4-5.

² Möller, A. Der Kampf gegen den Kiefernbaumschwamm. In Ztschr. Forst- u. Jagdw., Jahrg. 42, 1910, Heft 3, p. 133.

³ Möller, A. Der Kampf gegen den Kiefern- und Fichtenbaumschwamm. In Ztschr. Forst- u. Jagdw., Jahrg. 46, 1914, Heft 4, pp. 193-208.

during the last few years. In reason, all figures relating to loss in timber from decay, insects, lightning, etc., should apply only to such forested areas as are accessible at present or which will be in all probability accessible in the not too remote future. Inaccessible stands, whatever their protective value, do not represent timber values, and it is obviously wrong to include them in any estimate of the damage done to our timber stock on hand.

The rate of progress of decay in the individual tree is altogether unknown beyond vague guesses.

Hartig¹ has tried to figure the rate of growth of the mycelium, for instance, of *Fomes igniarius*. Möller² has made an attempt to figure the rate of growth of *Trametes pini* and resulting decay in *Pinus silvestris* from actual measurements in artificially infected trees. It is clear that unless such experiments are carried over a great many years, only the rate of growth of juvenile fungus plants starting from the infection can be measured, which can not be taken directly as a guide for figuring the growth of the older or mature fungus plants. Besides, the experiment is based upon the assumption that the fungus, after once having gained access to the interior of the tree, is independent of possible individual differences of its substratum, or, in other words, that the rate of growth is a fixed factor, irrespective of individual properties of the heartwood. This assumption has no solid basis. The rate of growth of the fungus plant, and therewith of decay, is undoubtedly one of the most inaccessible chapters of forest pathology, on account of the difficulty in finding a stable point of issue. There is at present no reliable method known of determining the actual extent of decay in the standing living tree. Indirect methods are the only means presenting themselves to-day; they leave much to be desired with regard to accuracy and can not be expected to yield results unless carried on over a long period.

What we do know is that decay in standing living timber from heartwood-destroying fungi causes very heavy losses and that decay is progressive. Sporophores develop on decaying trees, and the disease spreads through spores from one tree to other individuals of the same and sometimes of other species. Moreover, the decay starting from an incipient infection progresses in the heartwood of the individual tree until its most valuable lumber is destroyed. Decay being progressive, the cumulative risk from this source in long cutting cycles is therefore far greater than in the case of lightning or other injurious agents.

Unlike insects, heartwood-destroying fungi have few or no natural enemies; there is no such thing as "biological control" of decay.

¹ Hartig, Robert. Die Zersetzungserscheinungen des Holzes der Nadelholzbäume und der Eiche ... p. 116. Berlin, 1878.

² Möller, A. Der Kampf gegen den Kiefernbaumschwamm. In Ztschr. Forst- u. Jagdw., Jahrg. 42, 1910, Heft 3, pp. 129-146. (See p. 145.)

PERIOD OF TRANSITION.

American forestry stands now at the very beginning of a period of transition from the handling of virgin forests to actual forest regulation. The most urgent problem, therefore, consists in how to take care of our forests as we have them, with all their defects, with individual decadence and decay, and to leave them to future generations in as favorable a state as possible, judged by our very limited insight of to-day. At the present time the only means at the disposal of the Government to carry out any plans in forest regulation based upon what appears to us as sound silviculture is through timber sales. The Government does not and can not cut its own timber. It is therefore entirely dependent upon a highly variable outside factor with regard to the most important part of its silvicultural work, a factor over which it has but little control. All attempts at the regulation of yield must then be concentrated on timber-sales areas. A comparison between the area actually cut over annually and the total national-forest area that may eventually become accessible to logging operations will show the severe hardship under which the Government is forced to work. Moreover, timber sales do not always occur where they are most needed from a silvicultural point of view, nor do they always cover the entire natural units upon which it is desirable to prepare for a system of regulation. A comprehensive system of regulation on a larger scale following natural units is out of the question as long as the Government is not in a position to do silvicultural work on its own land where it is most needed.

The aim of the Forest Service at the present time consists less in how to do the greatest amount of good to future generations than in how to do the least harm and at the same time to do justice to our present-day conditions. Instead of exhausting our energies in sterile speculation of what might happen in 100 to 200 years from now, there is a strong tendency toward applying them first to the analysis of the most urgent needs of to-day and then to the exact and painstaking study of all the innumerable factors which enter into a comprehensive plan for the future structure of American forestry. It is well to remember that so far, not even the methods leading to the majority of such studies are worked out. The necessity of taking care of our present-day timber supply and of providing for the future in an extensive rather than intensive way has found strong expression in Chapman's¹ "American Method," where regulation is based not only on present volume and annual growth, but also on the "actual condition and amount of timber in the different age classes, with approximate knowledge of the behavior and condition of the age classes for an

¹ Chapman, H. H. Coordination of growth studies, reconnaissance and regulation of yield on national forests. *In Proc. Soc. Amer. Forest.*, v. 8, no. 3, 1913. pp. 317-326. (See p. 323.)

extensive future period." If "condition" is defined as state of health, not only as far as thriftiness of growth is concerned, but also with special regard to degree of merchantability as influenced by decay, the condition factor becomes a subject of pathological study.

Condition of the timber we hope to raise for the future, in the definition as given above, has a strong bearing on the possible regulation of yield. There can be no sense in figuring cutting cycles or rotation for future generations to follow unless we assume that our successors will find the area we have cut over covered with a stand not only apparently but really merchantable; in other words, with timber that is not rendered valueless by decay. The most ingenious speculation as to future yield is without any value whatever unless we have some way of figuring how long the steadily increasing but admittedly perishable timber stock can be left in the forest before it is liable to destruction by fungi.

The most important problem before us, therefore, is the determination in definite values of the condition of timber stock, present and future.

CONDITION OF TIMBER STOCK.

The condition of the timber as a factor in regulation may be expressed as the relation of the volume of timber destroyed or rendered unmerchantable by injurious agencies to the ideal volume of merchantable timber; or, in so far as forest regulation is interested not merely in the present but in the future, as the relation of the mean annual total loss to the mean annual increment.

It has already been pointed out that the concept of the relation of the mean annual total loss to the mean annual increment is without any value whatsoever as long as both factors are unknown. We are beginning to know in a small way something about the mean annual increment of certain species in certain types of some of the national forests. We are still completely ignorant as to the influence that the only silvicultural act of any importance open to the Forest Service, that is, cutting on timber-sales areas, will have on the increment of the remaining trees. This knowledge will come in due time. The value of the total-loss factor is altogether unknown. In order to attack this problem it is necessary to analyze it, to reduce it to its several components, and to study each in its turn. By synthesis the total loss can then be computed and the true relation to increment determined.

TOTAL LOSS.

The analysis of total loss already given shows that its components are known, but not their values. Of all these components the most important, the one that has the strongest bearing on the value of the stock of timber at hand, is loss from decay or heart rot caused by a group of heartwood-destroying fungi. Very young trees are not

susceptible to heart rot. No heart rot is possible before heartwood is formed. Unfortunately, we do not know anything about the formation of heartwood in our American species with relation to the age of the tree. The younger trees, while at present immune, will, in growing up and after formation of heartwood, become just as subject to heart rot as are their older companions. It is, then, of prime importance to know at what age living trees of a given species become particularly liable to attack from the one or more heartwood-destroying fungi that use their heartwood as a source of food. It is, further, of the utmost importance to know whether there are any conditions in the tree or outside of it that exert an influence over the development of the fungi once they have gained access to the heartwood of a tree to which they are adapted.

Beyond general statements to the effect that overmature trees do deteriorate from heart rots, very little information is to be gathered from American literature concerning the average age at which certain tree species become liable to attack from heartwood-destroying fungi. Greenamyre¹ mentions that in the Apache National Forest the decay in Douglas fir "no doubt largely offsets the growth" after the age of 210 years is reached.

Munger² gives a little more specific information:

The amount of decay found in living Douglas firs up to the time they are 150 years old or so is very small, but in mature and overripe timber there is a great deal of defect due to decay. . . . Douglas fir trees resist infection from fungi well until they become mature, when, because of the opening up of a stand, breakage, and scars due to the action of the elements and of fire and insects, and also because with advancing age their resistant power becomes less, they offer entrance to fungi.

It is not clear from the context whether Munger's figures are an estimate or are based on actual methodic investigation and measurements.

Findley Burns,³ in speaking of conditions on the Crater National Forest, gives the following information:

Many of the older Douglas firs are affected by a dry rot. . . . White fir is especially susceptible to decay, and many trees above 40 inches in diameter on the forest are so rotten as to be valueless, even for cordwood.

In the latter case, age is supplanted by diameter, which answers perfectly well if diameter invariably corresponds to age.

Barrington Moore and R. L. Rogers⁴ incidentally give some interesting notes on the age of infection of balsam fir, which on the

¹ Greenamyre, H. H. The composite type on the Apache National Forest. U. S. Dept. Agr., Forest Serv. Bul. 125, 32 pp., 4 figs., 1913. (See p. 31.)

² Munger, T. T. The growth and management of Douglas fir in the Pacific Northwest. U. S. Dept. Agr., Forest Serv. Circ. 175, 27 pp., 4 figs., 1911. (See p. 10.)

³ Burns, Findley. The Crater National Forest. U. S. Dept. Agr., Forest Serv. Bul. 100, 20 pp., 4 pls., 1911. (See p. 12.)

⁴ Moore, Barrington, and Rogers, R. L. Notes on balsam fir. *In* Forestry Quart., v. 5, no. 1, pp. 41-50, 1907.

area investigated was 50 years in pure stands and 85 years when mixed with hardwoods. They speak of butt-rot only, without specifying the cause; unfortunately, the numerical basis from which their figures are derived and their methods are not given.

The bearing on management of the age at which decay becomes a seriously damaging factor is very rarely realized.

Clapp,¹ in speaking of incense cedar and white fir, clearly recognizes that where these "inferior" species are also defective, "an attempt should be made, at least in selection stands, to reduce their rotation to one which will produce sound timber."

In a recent article, D. T. Mason² advocates a rotation of 100 years for western white pine, on the ground that this species on the average gives a maximum yield at this age and that from about the same age fungi, and particularly insects, generally succeed in doing a large amount of damage.

It would serve no purpose to continue quoting the few and scattered notes on the relation of age to decay, of a similar indefinite nature found in American literature. By way of consolation, it may be said that foreign literature does not abound very much more than our own in definite information regarding this point. Although the importance of the age at which forest trees are most liable to attack from heartwood-destroying fungi is frequently hinted at in German literature, Martin³ is the only German forester who, to the knowledge of the writer, has given more than a cursory discussion of the relation of this age to rotation. In speaking of the immense damage done in Prussian pine forests by *Trametes pini*, he attempts to show from somewhat meager material how the increase in loss from this cause should lower the rotation.

All computations of the amount of decay in German forests must necessarily be incomplete, since from an early age all undesirable individuals, including, as a matter of course, all trees with visible signs of decay, are eliminated in improvement cuttings. The result is a stand of a comparatively high degree of soundness. Even in such stands Martin finds (p. 688) that in a given district the percentage of decay in wood good for fuel only in the 100-year class was 11, in the 120-year class 22, in the 130-year class 31, in the 140-year class 37, and in the 160-year class 42. He points out that in unsound stands the felling age must be lowered in order to secure the maximum income. Martin⁴ again discussed similar ideas in 1910.

¹ Clapp, E. H. Silvicultural systems for western yellow pine. *In* Proc. Soc. Amer. Forest., v. 7, no. 2, pp. 168-176, 1912. (See p. 175.)

² Mason, D. T. Management of western white pine. *In* Proc. Soc. Amer. Forest., v. 9, no. 1, pp. 59-68, 1914.

³ Martin. Der Einfluss des Baumschwammes auf die Umtriebszeit der Kiefer. (Kritische Vergleichung der wichtigsten forsttechnischen und forstpolitischen Massnahmen deutscher und ausserdeutscher Forstverwaltungen.) *In* Ztschr. Forst- u. Jagdw., Jahrg. 35, 1903, Heft. 11, pp. 685-690.

⁴ Martin. Die Umtriebszeit der Kiefer in den Staatsforsten von Preussen, Bayern, Elsass-Lothringen, Hessen und Anhalt. *In* Forstw. Centrbl., Jahrg. 54, 1910, Heft 7, pp. 363-387.

Möller¹ touches upon the same point in a general way, without trying to give the problem a more solid basis by exact material. The following sentence is worth quoting:

Whilst the mean annual increment of the stand is slowly decreasing, the mean annual increment of decay is steadily on the increase.

Here is the clue to the proper silvicultural valuation of cutting cycles or rotation on a pathological basis. The time at which a tree or a stand is to be cut may range from a comparatively low age to the age of maximum production of lumber, according to the special needs the forester has in view; but the upper limit of this range should not lie beyond the period at which the gain from increment is offset by loss from decay, irrespective of the ideal amount of timber a sound tree or stand might produce under favorable conditions. Not to cut a tree or a stand in which increment is offset or exceeded by loss from decay, where cutting is possible, constitutes an unsilvicultural act. Gilman² informs us that silver fir in the Black Forest, Baden, Germany, "is unable to stand a long rotation, for after 100 years the per cent of rotten timber increases greatly." Here, the influence of loss from decay on rotation is clearly shown; but it is to be noted that the loss factor is derived in a purely empirical way and is not based on exact studies. Hemmann³ has published some interesting and exact studies on the damage done by *Trametes pini* in Scotch pine in a small area under regular management; that is, where the disease was partly eliminated by improvement cuttings.

All this somewhat scanty European material, valuable though it undoubtedly is for transatlantic forestry, is of very little help to us. What holds good for the managed forest raised in a century of careful nursing can not serve for more than a clue in genuinely or practically virgin forests, whether they be located in the United States, in Canada, in Chile, in India, or in Siberia. Again we are confronted with the necessity of working out our own problems in our national forests.

INFERIOR SPECIES.

Most of the timbered parts of the national forests, especially in the West, are practically virgin, seriously injured by fire, composed of even-aged or many-aged stands, and generally of more than one species, which are more or less exposed to heart rot caused by one or more specific fungi.

¹ Möller, A. Über die Notwendigkeit und Möglichkeit wirksamer Bekämpfung des Kiefernbaumschwammes *Trametes pini* (Thore) Fries. In Ztschr. Forst- u. Jagdw., Jahrg. 36, 1904, pp. 677-715. (See p. 712.)

² Gilman, E. C. V. Forest types of Baden. In Forestry Quart., v. 10, no. 3, pp. 440-457, 1912. (See p. 452.)

³ Hemmann. Über den Schaden des Kiefernbaumschwammes. In Allg. Forst- u. Jagdztg., Jahrg. 81, pp. 336-341, 1905.

A systematic study of the relative position occupied by the heart-rot factor in the economy of the forest presupposes a knowledge of the morphology and biology of the specific fungi attacking the species of which the forest is made up. Morphologically, most fungi of economic importance are well known; biologically, there is much left to be learned. The susceptibility of each host species to specific attack, the age at which a given species becomes liable to attack by the fungi adapted to live on it, the age at which a given species is liable to suffer appreciable loss from this source, the relation of accessory factors in the tree and outside of it to fungus growth, the relative loss caused by each fungus in its specific host—all these are fundamental problems which must be solved for every important fungus on every commercial species of our forest trees. So far, no definite and clear, comprehensive answer can be given to any one of these questions.

In determining upon a suitable starting point in the overwhelmingly large amount of work before us, the question is that of deciding where such work is most needed at the present time.

Leaving out of consideration such species as bigtree (*Sequoia gigantea*), which is never cut in national forests, and redwood (*Sequoia sempervirens*), which is hardly represented in national forests, the commercial timber of the national forests in the western part of the United States is composed of coniferous trees, such as pine, larch, spruce, fir, Douglas fir, hemlock, incense cedar, and western white cedar. They constitute the goods the Government has to offer for sale. Of these the pines cause least trouble. Pine lumber is eagerly sought and pays good prices; moreover, the loss from decay is comparatively small. In Government timber sales there is never any difficulty about pine timber; the more the Government has to sell on a given tract the better. Not so with the so-called "inferior species."

The term "inferior or undesirable species," as it is generally applied, is originally not a technical one. It is meant to designate those more or less heavily represented commercial species which suffer from a distinct prejudice on the part of the purchaser. If we could grow sound incense cedar, for instance, there would be a ready market and a good price for every foot, board measure, of it that the Government could offer on timber sales. Distinction should be made between species which actually yield technically poor lumber, even if sound, and species, on the other hand, which when clear and sound yield valuable material, but which are in general underrated by the purchasing public on account of the extraordinary prevalence of decay. An example of the first class is eastern hemlock. An example of the second class is incense cedar, which, although of excellent quality when sound, suffers from a very bad reputation among lumbermen,

because it is so very commonly rendered useless by dry-rot or pin-rot. The numerically and economically most important species of the accessible merchantable national forests in southern Oregon and California are sugar pine, Jeffrey and yellow pine, Douglas fir, white fir, and incense cedar. To these may be added, for certain localities, lodgepole pine, red and Shasta firs, western larch, Sitka spruce, western hemlock, and western red cedar. Of the six main species, all three pines command good prices. They are comparatively free from heart rot. White fir and incense cedar are in general so badly defective that, as Clapp¹ states, they are "under present conditions almost a drug on the market." Douglas fir stands in a class by itself. The value of its timber is well known; in fact, it competes with pine timber as far as quality for many purposes is concerned. On the other hand, Douglas fir is in a far higher degree susceptible to the attacks of several heartwood-destroying fungi, and, although it is not classed among the inferior species, the very prevalence of decay makes it less desirable than the pines, from a silvicultural point of view.

Incense cedar and white fir are frankly classed as inferior. Whether this view is correct or not, we must reckon with it as a powerful factor of influence in all timber sales where these species occur. They are the lower grade by-products of the factory, the production of which can not be stopped; it goes on in spite of what we may wish or what we may do. The logical conclusion appears to be, then, to concentrate all efforts on detailed and comprehensive studies of the properties of these by-products, desirable or undesirable, and to incorporate the results in a rational system of management, rather than to attempt to stop their production. The attitude of American foresters toward these and similar species is undoubtedly changing. There was a time when they were considered little better than weeds, to be gotten rid of as soon as possible and to be kept out of the forest wherever possible. This concept is giving room more and more to a consideration of how best to regulate the unavoidable reproduction of both species and how best to utilize the timber they produce.

The so-called inferior or undesirable species have their very definite place in the ecology of the mixed forest, and many examples could be cited from European experience of the disastrous results of an artificial change in representation of species and reduction of the mixed stand to a pure stand composed of an apparently more desirable species, without due consideration to the local soil and climatic conditions. Greeley² seven years ago expressed the opinion that "it is

¹ Clapp, E. H. Silvicultural systems for western yellow pine. *In Proc. Soc. Amer. Forest.*, v. 7, no. 2, pp. 168-176, 1912. (See p. 175.)

² Greeley, W. B. A rough system of management for forest lands in the western Sierras. *In Proc. Soc. Amer. Forest.*, v. 2, no. 2, pp. 103-114, 1907. (See p. 112.)

both impossible and undesirable to eliminate these species altogether." He specifically names white fir and incense cedar. Their aggressiveness makes it impossible to eliminate them, even if this were desirable. But more than one species, not so many years ago considered inferior, has now come into its own. The history of the lumber markets of Europe and our own country shows conclusively that with closer utilization necessitated by the growing scarcity of timber, the value of lower grades, as well as of so-called inferior species, is advancing more rapidly than that of upper grades or more valuable species. In the case of incense cedar this evolution may be watched at the present time. Up to a very short time ago incense cedar was "almost a drug on the market;" now even very short logs when sound are utilized for pencil wood and priced accordingly.

Concentration of study on the inferior species, therefore, promises the most immediately applicable results.

METHODS OF INVESTIGATION.

CHOICE OF SPECIES AND SITE.

Forestry is not interested primarily in the morphology and life history of a given heartwood-destroying fungus. Such studies, though indispensable and of the highest value, belong to an altogether different realm of science. The forester thinks in terms of trees, not of fungi; he concentrates on timber species to be protected or utilized, not on parasitic organisms, however interesting they may be from a mycological point of view. If forest pathology is ever to be of any value to practical forestry, all work and all conclusions must be focused on the tree, the species, as a producer of timber values and as a member of the forest community.

The fact that the same species may be subject to serious loss from several fungi and that the same fungus often works differently in different host trees complicates the difficulties naturally connected with all work for which a basis first had to be constructed. Partly for this reason, the writer first worked on incense cedar, which, so far as known, has only one heartwood parasite, *Polyporus amarus*. The studies described in the following pages were concentrated on white fir, because its management presents, perhaps, the most embarrassing problem of to-day on the Pacific coast and because, in by far the greater number of cases, serious loss is caused by one fungus only, *Echinodontium tinctorium*.

After deciding upon the species to be investigated, the choice of the sites for the study becomes the main question. One single type will probably yield interesting clues, but the result can not with impunity be applied to all sites and types within the range of the species. It is clear that studies within what might be termed the merchantable range of the species must be most important from a practical point of view. But inside of the merchantable range the species is subject to

so many varying conditions with regard to soil, climate, admixture of the species, and representation that here again typical areas must be chosen for independent studies. The more diversified the types studied and the greater the number of trees per type and in the aggregate, the more reliable will be the results.

The choice of the particular area to be studied is, of course, important. The unit of study should be representative, typical for the larger unit. In general it will not be difficult, with some care, to make the proper choice.

The result of the writer's studies, still unpublished, on the critical age of incense cedar served to work out the methods which should be applied in a modified form to the at present more important investigations on white fir. European precedent could not be used; Martin, Möller, and Hemmann worked on managed forests. New methods to suit our conditions had to be evolved.

The only satisfactory result could be expected from careful dissection and analysis of as large a number as possible of trees of different ages. Unlike other investigative work, studies of this kind can not well be carried out on timber-sales areas where the actual felling and bucking of the trees is done by the purchaser. The purchaser is none too willing to cut trees containing rot unless he is compelled to do so; much less does he care to buck such trees, which, after all, are the ones from which we must expect most valuable instruction. He is not obliged to cut trees below a certain diameter limit, which, of course, can not be left out. All this is particularly true for the so-called inferior species, the handling of which often comes so near being a loss to the purchaser that any additional cost would work a distinct hardship. For the same reason it is impossible to have the trees on timber-sales areas bucked in odd log lengths, as dictated by the irregular and varying extent of the decay. As will be seen, a few of the notes used for this study are incomplete, because they had to be taken in connection with timber sales.

It becomes necessary, therefore, to carry on investigations of this kind on representative areas chosen for the purpose and to have the systematic cutting and dissecting of the trees done by crews, involving much work and a large expenditure. This way of handling the problem has proved to be the only feasible one; and, as long as immediate results may be expected, which if properly applied must lead to very considerable savings as well as to progress in silvicultural management and forest regulation, the expense and work seem to be justified.

FIELD METHODS.

Before the actual felling begins, notes are taken first on the larger forest unit of which the area to be studied forms a part, such as elevation, climate, water table, soil in general, history (lightning and

forest fires), composition, representation of species, ground cover, possibilities of future logging operations as a first step toward regulation, and local valuation of the species; more detailed notes of a similar nature then describe the particular type and stand which is the object of the study.

When a new species is to be studied, trees of all sizes and all conditions must be cut. It is absolutely necessary constantly to guard against picking out trees either because they appear sound or because they are liable to contain decay. According to the attitude of mind of the investigator there will always be a tendency, conscious or subconscious, to think of the final result and accordingly to choose particular trees for felling. The personal factor must necessarily influence the result of the equation and can not be warned against too emphatically.

Correctness and accuracy in detail are the basis of any scientific work worthy of the name. Where the one chief aim is to substitute reliable figures for guesswork, to establish facts, from which conservative interpretation may derive certain working rules, observations and measurements can not go too far in detail and exactness. On the basis of experiences in the incense-cedar studies, a printed sheet was prepared, to be used in a loose-leaf binder of pocket size, in which a set of standard notes was to be entered. Each sheet contains the notes for one tree only.

The first notes to be taken on a tree chosen for analysis are general; they are taken before the tree is felled. Slope, exposure, soil composition, and moisture are taken for the individual tree; the next notes concern the outward appearance of the tree, crown class, as far as can be determined, condition of the bole, whether forked or leaning, presence and degree of fire scars, resin flow on butt or bole, swellings, sporophores of fungi, condition of the crown, development and state of health; in short, all notes that can and should be taken from the standing tree. During this time an assistant takes the diameter breast high and sets the fellers to work. The notes on the bole and crown are completed when the tree is down. They concern the presence of mistletoes or needle diseases, witches'-brooms of any kind, their number and relative importance, presence and extent of lightning injury, condition of top, and similar data that might have a bearing on the pathology of the species. It goes without saying that the tree is felled at the regulation stump height of 18 inches, never higher unless absolutely unavoidable. The assistant now measures the height of the tree from the ground and counts the age at the stump. This, of course, does not give the true age; but instead of adding, more or less at random, a small number of years corresponding to the height of the stump, it seems advisable to accept the count at the stump as the age. The fewer the figures based on an estimate

that are included in our computations, the narrower will be the margin of error. Besides, in practical work, the age is generally counted at a stump height of 18 inches, and, since for all purposes of management we have to deal with the standing tree where diameter is the only indicator of age, it is of little importance whether the age counted is absolute, within narrow limits, as long as all figures are directly comparable with each other. Moreover, in practice it is impossible to have all trees cut at exactly 18 inches. With the greatest of care, the stump height will vary. It is an easy matter, where desired, to add a number of years corresponding to stump height as soon as reliable figures, which now are lacking, are obtainable.

The limbs and branches are now lopped off and the brush piled for burning.

In the bucking of the bole some judgment should be used, guided by the object of the study. We want to find all traces of decay in the bole and take exact measurements of them. Obviously, then, the aim of the dissection must be to open up the tree in such a way that no decay can escape the observer. It would not do, therefore, to buck all trees in even log lengths of the usual commercial measures. A straight, clean bole without any blemish whatever is bucked in 16-foot logs, which then are individually split; this will, as a rule, bring out any hidden decay. Both the cross sections at the opened surfaces of the split wood must be searched very carefully for any abnormal sign. This makes full knowledge of the properties and aspect of the normal wood a prerequisite. In the beginning, therefore, it is advisable first to study very closely the sound, normal wood of the species, until the operator is able to detect at a glance and automatically any deviation from the normal. The success of the study hinges upon the development of personal skill in judging wood. In order to prevent the dulling of this sense during the course of the work, check studies of perfectly sound wood will prove very beneficial. Any slight real or apparent deviation from the normal in physical properties or aspect, particularly in color, must be followed, of course, to its source.

Trees without any blemish are rare; generally there is either some irregularity in form, fork, unusually heavy branching, or there are sporophores of fungi, badly healed-over branch stubs, swellings, depressions, catfaces, fire scars, lightning scars, or frost cracks and frost ridges. In choosing the proper places for bucking, it is generally advisable to start at the most salient malformations or defects; they will often lead to the focus of decay, if there is any. In case of failure, the less prominent defects are investigated, and so on down the line until there is no doubt left that no decay is present in the bole. Particular attention must be given to branch stubs, which, by extending through the sapwood to the outside of the tree, offer an easy

entrance into the heartwood. After infection has taken place in this manner, the mycelium grows in the heartwood. Before sporophores are formed it is often impossible to locate the presence of the mycelium in the tree. This is particularly true for quite young fungus plants, and the possibility that the beginnings of decay may be hidden in a log, both ends of which are perfectly sound, must ever be present in the mind of the operator. It is impossible, except by mere chance, to detect the very first stages in the field. As soon as the fungus plant, the mycelium, has reached a certain stage of development, represented by visible alterations of the wood, there is no excuse for overlooking it. As a rule, the oldest part of the focus of infection shows the strongest evidence of fungus growth expressed in what we call decay. Decayed stubs are a valuable index as to decay in the tree, although there are cases where, for unknown reasons, the infection does not, or only very slowly, result in more extended decay. Duesberg¹ has advocated the location of infected trees by the presence of diseased branch stubs. Such decayed branch stubs may also correspond to that stage of development of the mycelium just before the formation of sporophores through the stub takes place. In this case also decayed branch stubs will be most valuable in detecting heart rot in the bole.

If decay is found, it is followed throughout its entire extent by splitting the logs with wedges and with the ax. To avoid this often very tedious and time-consuming work, splitting with black powder has been tried, with rather unsatisfactory results. In partly decayed logs the splitting is very irregular, and the wood surfaces are badly stained and blackened, the stain generally interfering with the inspection of the wood. When the full extent of the decay is determined, notes are taken on the character of the discoloration or decay and on the stage of development, and the extent is carefully measured. For studies of this kind it will often be sufficient to note the extent in length in linear feet, under the assumption that in low-priced species any lumber that might be cut from an affected part of the bole will not pay for its transportation to the mill. In higher grade species the lateral extent must always be considered.

This complete and detailed dissection usually allows the tracing of the decay to some point of entrance, whether fire scar, lightning wounds, frost cracks, or branch stubs. The result is entered on the sheet. Finally, any notes not specially foreseen on the sheet are entered under "Remarks."

As a general principle, all observations that can be expressed numerically must be given in figures. It is essential that all esti-

¹Duesberg. Das Aufsuchen von Schwammstämmen in Kiefernbeständen vor der Ausbildung von Fruchthäusern. *In* Ztschr. Forst- u. Jagdw., Jahrg. 44, Heft 1, pp. 42-43, 1912. Reviewed in *Forestry Quart.*, v. 11, p. 251, 1913.

mating should be reduced to a minimum. In order to render this unavoidable minimum, which undoubtedly constitutes a source of error, as innocuous as possible, the operator must constantly be on the guard against any variations of his standard by which he is guided, consciously or subconsciously, and from time to time check up on this standard. The notes to be taken by estimate concern degree or grade. Soil moisture, seriousness of wounding by fire, degree of resin flow (whether light or heavy), condition of crown (for example, unhealthy color or thin foliage and the presence and degree of needle diseases in their bearing on the thriftiness of the tree), degree of discoloration of the wood—all these can be expressed in figures only with difficulty. Even if a scale of 1 to 10 is adopted for these purposes it is extremely difficult to decide whether the change of color of the wood under the influence of the fungus is to be classed as 6 or 7. The writer therefore has adopted a simpler system, which, while far from being exact, at least avoids gross errors and at the same time is graphically clear and sufficiently elastic to cover all cases of importance. It expresses the information asked for on the sheets with the aid of crosses and dashes. A dash after "Fire scars," for instance, is negative; there is no fire scar. One cross, x, is simply affirmative; there is fire injury, but it is not to be considered as serious. Two crosses, xx, indicate that the fire injury is fairly bad, distinctly beyond the mere presence of an injury. Three crosses, xxx, emphasize the damage; the fire injury is unusually large and severe. By putting the crosses in parentheses, (x), or x (x), or by hyphenating two consecutive degrees, x-xx, intermediate grades may be given when desirable; and finally the last grade, xxxx, can be used in very extraordinary cases for emphasis. In general, x, xx, and xxx will answer the purpose. Thus, the estimate is really reduced to a simple system of three grades, which allows for a more constant mental reference to the standard. Whenever necessary or feasible, special notes or measurements are entered after the crosses. This system is also used in our tables. With the exception given above, all these notes are taken by the chief of the party. Meantime, the assistant counts the age and diameter at every cross section, takes growth measurements, measures the width of sapwood and the length of the sections, and records such other data as may present themselves in the course of the work.

In complicated cases, drawings or notes are added on blank sheets bearing the numbers of the trees.

PATHOLOGY OF WHITE FIR.

The studies on white fir presented in the following pages are not meant to give definite results valid for the entire range of the species. They were primarily intended to develop the more practical methods

to be employed and secondarily to gain reliable material to be used in a chain of similar studies on different types, from which conservative interpretation may derive final conclusions. They are given here as examples only, as illustrations of the general considerations presented in this bulletin. Since making these studies, others on a larger scale and on different types in different parts of the range of white fir were carried out with improved methods during the summer of 1913.

A short review of our present knowledge of the pathology of white fir will be of help in the discussion and interpretation of the data presented in this paper.

White fir (*Abies concolor* (Gord.) Parry) can not be called a decadent species; on the contrary, it is very aggressive and possesses remarkable elasticity and resistance to injurious influences. Its tolerance to shade is well known. Not only does it survive dense shading to a high age but it responds readily to light and then reaches considerable diameter and height in perfect health, provided it has not been seriously wounded and infected. The oldest tree examined in this study was 258 years old; it was badly suppressed and but 67 feet high with a diameter breast high of 17.4 inches. In the trees tallied between the ages of 130 and 140 years, the diameter breast high varied from 8.8 to 30.7 inches and the height from 47.5 feet to 125 feet.

In speaking of tolerance which allows suppressed trees to reach a high age under the most unfavorable conditions and with a minimum of annual growth, the behavior of the species with relation to light is generally meant; but this toning down of the life functions of the tree, visibly expressed in growth, very often has nothing to do with lack of light. A tree may become suppressed to the lower limits of its tolerance by any agent severely attacking any of its vital organs. Of these, the organs of the crown are both most easily accessible and most sensitive; hence, the heavy damage resulting from a serious attack by insects devouring and killing the foliage or by leaf-inhabiting fungi. White fir is subject to a disease of the foliage caused by *Lophodermium nervisequium*, which often kills all needles except those of the current year's growth. The loss in foliage surface, and therefore in photosynthetic capacity, may suppress a white fir just as lack of light would. Witches'-brooms caused by *Peridermium elatinum* on white fir are not common. They are very rarely of such development on the tree that they should be classed as an injurious factor to be reckoned with. Incidentally, it should be mentioned that the swellings and cankers so commonly connected with *Peridermium elatinum* on *Abies pectinata* in Europe are unknown in *Abies concolor*. On the other hand, very similar swellings and cankers caused on white fir by *Razoumofskyia abietina* Englm. are extremely common. The

actual connection is readily established by either the living mistletoe growing out from the swellings or by the small cuplike remains of the stem bases. The swellings render the affected part of the bole unmerchantable. When they break open into what are termed cankers, infection by fungi very readily takes place and a focus of heart rot forms, very much as in the case of *Peridermium elatinum* on *Abies pectinata* where *Polyporus hartigii* and *Agaricus adiposus*¹ commonly start from cankers caused by the rust fungus.

The mistletoe cankers very often are the cause of white-fir stems breaking off in a storm, just as *Peridermium* cankers affect *Abies pectinata*. This mistletoe is more generally found in the middle or lower parts of the crown; infection takes place only on the very youngest twigs.

Another mistletoe (*Phoradendron bolleanum* (Seeman) Coville) nests high up in the top. It often kills the leader; volunteers spring up, which are frequently killed in their turn. Considered in its relation to the totality of leaf functions, the loss from a killing of the leaders can not be very serious, although it may count in combination with other injurious agencies. The same is true for the host of minor parasites and injuries to which the peripheral growing parts—in contrast to the column of wood—are exposed.

We have seen that the wood of the living tree itself is generally immune to attack from heartwood-destroying fungi as long as it is protected by bark and sapwood. The few exceptions, it seems, are of no great importance in the case of *Abies concolor*. *Pholiota flammans* is not uncommonly found in white fir and seems to take the place of *Armillaria mellea*. The exact damage done is still to be studied. *Fomes annosus* is not yet reported on white fir to the writer's knowledge. *Polyporus schweinitzii* is not common on the species. All other fungi causing decay can not enter the living tree except through some opening, as far as is known at present.

In white fir, as in other coniferous trees, small superficial wounds are readily covered over with resin from the bark; this natural dressing does not allow fungus spores to germinate or the hyphæ to develop after germination. Now, white fir is distinctly poor in resin. Large superficial wounds may therefore prove to be more serious. If the bark is destroyed, the cambium is killed and the sapwood dries out and cracks. Through these cracks air gains access to the interior of the tree and must in some way alter the chemistry and physics of the heartwood. The spores of heartwood-destroying fungi lodge in the cracks and upon germination may find a well-prepared substratum in the heartwood. Fungi, like all plants, make certain specific demands as to the chemical composition, water content, oxygen, etc., of the substratum they live on. Given the proper temperature

¹ Hartig, Robert. Lehrbuch der Pflanzenkrankheiten. Ed. 3, p. 153. Berlin, 1900

and the species of wood on which, for instance, a fungus like *Echinodontium tinctorium* (Indian-paint fungus), the most common destroyer of white-fir heartwood, can exist, its growth will still be dependent on the presence of heartwood of a certain character and on the water content of the heartwood. This is evidenced by the fact that decay is so commonly found in concentric development at a certain distance from the sapwood. The heartwood contains water in varying degrees, although it does not lift water like sapwood. But there is nothing surprising or irrational about the assumption that the water content of the heartwood will depend more or less on the water movement in the sapwood. The water in the heartwood of conifers is found in the membranes of the tracheids, not in the lumina. In a normal sound tree, heartwood of a given age and diameter surrounded by sapwood of normal width, corresponding to a certain crown development, will contain approximately a standard amount of water. Decrease in crown activity through some cause or another (suppression, injury to the crown, etc.) will soon be expressed in a rapid progress of heartwood formation, leaving only a narrow strip of sapwood, through which very much less water will move upward to the crown than in the normal tree. We may safely assume that the water content of the heartwood will change to a certain degree with the amount of water moved upward in the sapwood. The water content of the sapwood changes, furthermore, with age, and also with the season. Both changes must also appear, although in a far less degree, in the heartwood. Münch¹ has emphasized, in a series of very interesting papers, the relation of wood-inhabiting fungi to the water and air content of the host tissues. Water-logged tissues are inaccessible to these fungi; a certain minimum of air, as Münch expresses it, must be present in the tissue in order to allow the development of the hyphæ.

Variations in the water contained by imbibition in the cell membranes must influence the degree of humidity of the air in the lumen of the cell itself; it is quite probable that this factor also plays a rôle in the distribution of hyphæ in the wood.

What percentage of water in the cell membranes and of air in the lumina of the heartwood presents the optimum for the development of *Echinodontium tinctorium* and other similar fungi we do not know; but evidently there must be an optimum, a maximum, and a minimum. Any factor influencing the quota of water and air in the heartwood must, therefore, be of great importance. Cracks in the sapwood

¹ Münch, Ernst. Die Blaufäule des Nadelholzes. In Naturw. Ztschr. Land- u. Forstw., Jahrg. 5, 1907, Heft 11, pp. 531-573; Jahrg. 6, 1908, Heft. 1, pp. 32-47, 33 figs.; Heft. 6, pp. 297-323.

Münch, Ernst. Untersuchungen über Immunität und Krankheitsempfänglichkeit der Holzpflanzen. In Naturw. Ztschr. Forst- Land u. w., Jahrg. 7, 1909, Heft 1, pp. 54-75, 5 figs.; Heft 2, pp. 87-114; Heft 3, pp. 129-160.

Münch, Ernst. Über krankhafte Kernbildung. In Naturw. Ztschr. Forst- u. Landw., Jahrg. 8, 1910, Heft 11, pp. 533-547; Heft 12, pp. 553-569, 2 figs.

reaching to the heartwood admit air, and by evaporation change the water content of the heartwood; by oxidation, changes in its chemistry probably also take place.

The change must necessarily be intensified, the more serious the injury. Wounds exposing the heartwood heal over very slowly, and the heartwood which receives all its water from the sapwood must be modified very markedly in its chemistry and physics, particularly in its water and oxygen content, by the long exposure to the air. Moreover, from the time the injury happened until the time the wound is completely healed the heartwood is directly exposed to inoculation from spores of wood-destroying fungi adapted to white fir. Although the production of spores by a sporophore is enormous, by far the greater number are carried by air currents to places where they can not germinate for lack of moisture; many are intercepted by the natural screen ("forest screen") formed by the foliage and trunks of uninjured trees or by trees to which they are not adapted, and only a very small number finally land in the cracks of exposed sapwood or on exposed heartwood of white fir of the proper age. Of these, again, a very small percentage find temperature and moisture favorable for germination. This explains the fact that so many trees, although badly wounded, are not infected. But it stands to reason that every year during which the heartwood remains exposed adds to the danger of the tree becoming infected.

By far the deepest wounds are caused by fire. Although in white fir the danger in repeated fires feeding on the pitch flow following a first injury is comparatively slight, and although the lack of resin in the wood does not favor the hollowing out of the interior of the tree as it does in yellow pine, fire frequently causes very long wounds, which reach into the heartwood.

Spores can gain entrance to the heartwood through open frost cracks. Low temperatures and sudden drops of temperature are common throughout the range of white fir. Inside of the range they are more or less confined to certain localities and zones.

Lightning in white fir generally causes more or less superficial wounds. The peculiar injuries to be traced to lightning in white fir present many interesting features. Here we are only interested in injury which might lead to the infection of the heartwood. As in yellow pine, lightning sometimes tears long strips of bark off the tree and leaves the cambium and sapwood unprotected. In such cases both die and dry out, with the result that cracks in the sapwood lead into the interior of the tree. Smaller superficial lightning wounds locally kill the sapwood, which is very commonly attacked by secondary fungi, which do not do very serious damage. However, logs with lightning injury of this kind are liable to be thrown out as culls, although they generally contain some sound heartwood.

Other causes of serious wounds are comparatively rare. Occasionally a falling tree will brush off part of the bark of its neighbor. If the wound is large, the exposed sapwood dries out, cracks, and the heartwood becomes exposed. Very rarely a living tree shows signs of early girdling by rodents. Girdled trees as a rule are killed within a short time.

With very few exceptions the entrance of the fungus into the tree can be traced to one or more of the wounds just discussed. Occasionally, however, a tree showing no wounding at all is found to be decayed. In such cases the only means of entrance for the wood-destroying organism is through knots.

White fir prunes itself very poorly; the wood of the twigs is tough, hard, and resistant, and the branches do not break off very readily. Later, dead twigs may break off; in the cracks of the wood of the stubs spores of fungi may find proper conditions for germination and, once established, use the pin knot as a bridge from the exterior of the tree through the bark and sapwood into the heartwood. This is particularly true for twigs in which heartwood formation has begun. In this sense the opening afforded to fungi by a pin knot that is not healed over may be likened to a wound. The opening formed by the pin knot, however, is too small to materially influence the chemistry and physics of the heartwood of the tree.

White fir is not exposed to a great number of heart-rot fungi. *Polyporus schweinitzii* is not common. *Polyporus sulphureus* and *Trametes pini* are rather rare. The parasitism of *Fomes pinicola* is not fully established, at least not in white fir. The writer has found it on thrifty sugar pine in central California, where it was undoubtedly parasitic in the sense of attacking the sound heartwood of living trees through an open fire scar and extending toward the sapwood. There would be no incongruity in assuming that it may also occur parasitically on white fir; in fact, a number of observations rather speak for the correctness of this assumption.

By far the most serious danger to white fir throughout its range comes from *Echinodontium tinctorium* Ellis and Ev. This fungus seems to be particularly adapted to *Abies concolor* and does not appear on many other species. In California it is, though not very often, found on *Abies magnifica shastensis* and also rarely on Douglas fir. This fungus must therefore be considered as the chief fungus enemy of white fir. The sporophores are easily recognized. They are rather large, from 2 to 10, 12, and more inches in width (measured horizontally from side to side where they are attached to the tree), distinctly hoof shaped, with a black, dull, cracked, rough upper surface, and a lighter, grayish, level under surface, which is thickly set with hard, coarse spines. In young specimens the under surface is whitish and rather dædaloid prior to breaking up into spines. The

interior of the sporophore is vividly rusty red. This rusty color is most characteristic of the fungus and repeats itself very often in the decayed tissues of the host. The sporophores are never formed on the bark of the tree; invariably they appear from the under side of stubs of dead twigs or branches, and commonly the rusty color can be followed through these stubs or knots. As the sporophore is nothing but the fruiting body of the mature fungus plant living in the heartwood of the tree, which alone it is able to attack, every sporophore is a certain sign of far-reaching decay in the tree. The typical rot may be characterized as a stringy brown rot. Wood in this stage of decomposition is brown, with rusty reddish streaks, and becomes distinctly fibrous and stringy. Following the rot away from its maximum of development, we find wood still brown, with rusty streaks, but quite firm. Farther away, the brown color becomes less noticeable, the rusty color disappears, and finally we come to a point where the wood seems to be sound enough to be sent to the mill. A little care exercised in examination, however, will show in this seemingly sound wood the presence of small light-brownish spots and discolorations, particularly in the summer wood, intermingled with horizontal burrows, which at first glance could almost be taken for very shallow insect burrows. The burrows are not easily detected on a cross section. The small brown spots, which give the wood a faintly brown, mottled appearance, cause the entire cross section to be slightly darker than normal and discolored; but they show up very much more clearly in a longitudinal section. A small piece pried out of the end of the log with a hatchet or strong knife gives sufficient information about the real state of health of the log. This timber at present invariably goes to the mill and without doubt furnishes the lumber that, after being sawed, dries out and by becoming brittle causes the well-known prejudice against this species. It is often characterized by a peculiar sour smell and by a spongy consistency of the wood.

Cull from decay in white fir, therefore, includes not only typical rot but also this discolored material, which, although not distinctly rotten, is already under the influence of the advance guard of the fungus mycelium and will become completely decayed later on. For this stage of incipient, or, better, latent decay, the writer proposes the term "advance rot," which is used throughout this bulletin.

DESCRIPTION OF AREAS.

The three areas chosen for investigation are located on the Crater National Forest, in southwestern Oregon, all of them in the neighborhood of the Upper Klamath Lake, a large shallow basin with vast swamps, into which unusually large springs of clear cold water empty themselves. Very few streams of running water come from the

surrounding mountains. Dense timber frames the swamps and extends up the slopes to the mountain tops. The elevation of all three tracts varies from 4,150 to about 4,400 feet. Low winter temperatures and severe lightning storms are frequent in the entire region. Two of the tracts, the Pelican Bay Lumber Co. sales area and the Odessa ranger-station tract, are situated on the west shore of the lake. They are about 2 miles apart and present conditions so much the same that they can be considered as one.

The Pelican Bay tract on the west side of Pelican Bay lies, as far as the area covered by this study is concerned, along the slopes; the aspect is east to northeast. That is, it is exposed to cold wintry winds, sweeping unbroken across Upper Klamath Lake. We may expect frost injury. The volcanic soil is fairly deep and loose; the humus layer is rather shallow. There are no rock outcrops. The underbrush is composed of *Ceanothus*, manzanita, and some chinquapin.

The Odessa ranger-station tract is far less steep than the Pelican Bay tract. A considerable part of it is a gentle slope, almost level. The general aspect is north; presumably the tract is less exposed to sweeping winds of very low temperature. The soil is decomposed lava, but richer in humus than the Pelican Bay tract. Outcrops of rock are frequent. There are a number of large springs in the neighborhood. The underbrush is rather dense and is composed of *Amelanchier alnifolia*, *Ceanothus velutinus*, with some *Salix* sp.; the ground cover consists of *Ceanothus prostratus*, *Berberis aquifolium*, and *Symphoricarpos racemosa*.

The third tract, the Otter & Burns sales area, lies about 15 miles north of the north end of Upper Klamath Lake. The tract is level, the soil very loose, sandy, decomposed pumice, with no indication of rock. Under the influence of the Fort Klamath Valley with its swamps, the atmospheric humidity is rather high, as is evidenced by the rich lichen flora, *Alectoria fremontii* being common. Thus the immediate surface of the soil is kept damp, and litter disintegrates very rapidly. The humus is about 1 to 2 inches deep; the soil immediately underlying it is remarkably well drained. The rapid humification in the top layers favors the development of mycorrhiza on the roots of white fir in surface strata. White fir seedlings show a thick matting of mycorrhiza, confined to the same strata of a certain humification, and a very long taproot seeking water. Yellow-pine seedlings also develop a taproot, but the mycorrhiza rootlets are found at a greater depth than those of white fir. They are not as closely bunched as in white fir and are distributed over a larger area in a vertical direction. The underbrush is formed by *Ceanothus velutinus* of medium density, from 4 to 6 feet high, in a uniform cover.

On the two tracts near the lake white fir is mixed with yellow pine and Douglas fir, a little incense cedar, and a very little sugar pine. On the Otter & Burns tract the stand is composed of yellow pine and white fir, with occasional lodgepole pine.

On each tract conditions were more or less uniform, differences in elevation were negligible, and neither deep gulches nor steep slopes had to be figured with as disturbing factors. All in all, 160 trees were dissected and notes taken on all factors which possibly would have some bearing on the subject of this bulletin. In operating, the tracts were not clean cut; that is, not every white-fir tree in the area was felled and examined, since it was not the object of the study to establish a cull per cent for that particular region.

The data obtained are from selected trees. On the Pelican Bay Lumber Company's sales areas the trees, of course, had all been marked by the Forest Service officers in charge; on the Otter & Burns sales area some trees were marked, and others were felled independently of marking. On the Odessa ranger-station tract all trees examined were felled for our special purpose. The representation of trees of different ages, diameter, and height classes on the three tracts, therefore, is not expressed correctly by the number of trees examined on each tract.

LOCAL PATHOLOGY OF WHITE FIR.

The pathology of white fir in the Upper Klamath Lake region is comparatively simple. Of injurious factors of an inanimate nature, fire, lightning, and frost are common.

Very few species of fungi inhabiting living white fir are found on the three tracts. As we are mainly interested in the pathology of the wood, the occasional occurrence of *Peridermium elatinum* and of *Lophodermium nervisequium* becomes an entirely negligible factor.

Of heartwood-destroying fungi in living white fir, *Echinodontium tinctorium* is by far the most common, and sporophores are numerous. About 75 per cent of all cases of decay were due to this fungus. Occasionally decay may with some certainty be traced to *Fomes pinicola*. In one case a sporophore of an *Irpex* was found in the decayed hollow of the trunk. *Trametes pini* is missing altogether, though found occasionally on neighboring sugar pine. Decay caused by *Polyporus schweinitzii* was found in several cases, never with sporophores.

In other cases the decay was too indefinite to allow an identification of the fungus causing it. This is particularly true for the many cases of localized advance rot connected with scars from diffused lightning.

The preponderance of *Echinodontium tinctorium*, especially in connection with really damaging decay, is so marked that in this study all important cases of decay are considered to be caused by this fungus.

A study of the fungi destroying down timber lies beyond the scope of this bulletin. The only practical aspect of their activity lies in the fact that down timber, limbs, branches, twigs, and needles are decomposed very rapidly.

It is evident that all the points discussed in the preceding pages must be kept in mind in taking field notes. But this is not sufficient. Work of this kind has very much the character of an exploration; surprises and discoveries are possible at any point of the road, and it is therefore indispensable constantly to be on guard in order not to overlook any phenomenon worthy of observation.

TABULATION OF DATA.

The next step is proper tabulation of the data obtained. The three tracts were so close together and conditions so similar that they were considered as one, and all notes were combined. Separate interpretation of the notes of each tract showed differences only in detail. The procedure was as follows:

A first table was compiled from the field notes giving all important data as well as all such data which might have a bearing on the subject of this bulletin. As we are particularly interested in the problem of the relation of age to infection and subsequent decay, a second table gave the same notes arranged progressively by the ages of the trees examined. This table formed the basis for further operations.

The youngest tree dissected was 60 years old, and it is the first to show decay (Table I). The possible age limit of infection is therefore at least 60 years; it is probably lower. But in practical forestry we do not seek an answer to the question of the earliest age at which a tree might become infected, interesting as this is from a mycological point of view, but, rather, from what age may we with reasonable certainty assume that serious decay becomes so prevalent as to distinctly impair the merchantability of the timber.

The tree in question has a diameter breast high of 10.1 inches; it is 44 feet high. A healed-over broad scar still visible externally at 2 to 8 feet above ground corresponds to an internal scar, reaching from 2 to 10 feet, and was probably caused by lightning. The injury happened 22 years ago and was distinctly superficial; the deterioration, in the form of a slight discoloration of the sapwood, follows this scar only, without extending any farther into the wood. This superficial damage does not render the affected logs unmerchantable. For practical purposes, therefore, such cases may be disregarded; they are negligible. In the interpretation of our material, the character and the degree of the damage must be considered with special relation to their bearing on the merchantability of the lumber. Not only the extent in longitudinal direction but also the distribution of the decay over

the cross section enter into the valuation of this factor. In the present study, the lateral extent of decay, the distribution over the cross section, was estimated, as it is in practical scaling. Actual measurements are difficult to take, on account of the immense variability of the decay. In Table I, decay which neither in lateral extent nor in degree was considered sufficient to seriously injure the merchantability of the part affected was marked as negligible. The longitudinal decay was taken in linear feet, and the entire length was considered as affected, in order not to complicate the computation too much. We must distinguish between superficial decay of the sapwood and the more serious decay of the heartwood. Figures of superficial decay of sapwood are given in brackets (Table I, column 5).

The next trees are sound. A negligible decay occurs in a tree 73 years old. Its diameter breast high is 11.2 inches; its height 58 feet. The light decay started from an internal scar, caused by fire 23 years ago and healed over in 5 years, but it remained in close proximity to the scar without spreading. Again, a number of sound trees follow. Then the first more serious decay appears.

The tree in question is 84 years old, its diameter breast high only 8 inches, height only 45 feet. Both fire and lightning have played havoc with this individual. An open scar extends from the ground 21 feet up the bole. The tree is quite evidently not in good health, the sapwood is very narrow, and the crown is lopsided and very short. Even in this case the decay follows more or less the open scar, but it is sufficiently serious to cull the affected parts in so small a tree; in a larger and thriftier one the damage would be called more or less local and a nominal deduction made in the scale. From a lumbering point of view this tree may be disregarded.

So far, all trees considered had been either thrifty or not very seriously wounded. Here we have an obviously suppressed, unhealthy, and badly wounded tree; it presents at the same time the first case of decay that is not to be called negligible. The following trees are sound; then follows a negligible trace of decay in an 86-year-old tree, badly suppressed (diameter breast high 4 inches, height 13 feet), grown in dense shade, with a remarkably small crown and with a healed-over frost crack, but no other wounds. After several sound, fairly thrifty trees follows a tree 87 years old, badly suppressed (diameter breast high 7.8 inches, height 39 feet), with a very short crown, wounded badly by fire and lightning (open scar from ground to 18 feet), and with decay following more or less closely the open scar.

From these and the following trees, it appeared possible that with increasing age the crown class, or rather the degree of suppression and dominance, played a rôle with regard to the extent and seriousness of the decay. Preliminary studies on incense cedar had given the same indications. It seemed desirable, therefore, to express this degree of

suppression and dominance by a figure which would allow direct comparison between trees of the same age. Height alone would be misleading. Volume table figures can not be used, since they are based on sound normal trees. The relation of height to diameter breast high, expressed in total volume, was thought to be a safer index. The object being to obtain directly comparable figures by ages and not the exact volume, the tree was considered as a perfect cone over the stump, at which we had taken the ages. From somewhat scanty, but individually reliable notes, the diameters at the stump (diameter outside bark 18 inches) were obtained, and from these and the height the volume of the cone in cubic feet was computed.

TABLE I.—*Fundamental data on the pathology of the white fir.*

No. of tree.	Age.	Volume (cubic feet).			Character of wounds.
		For each tree.	Average for trees of same age.	Of rot, including advance rot (percentage of total volume).	
1	2	3	4	5	6
136.....	60	11.3	15(?)	¹ [34.2]	Lightning.
105.....	69	25.1	19	—	Leader healed in.
145.....	71	11.8	20	—	No wounds.
135.....	72	18.8	20	—	Very slight lightning.
147.....	72	7.7	20	—	No wounds.
143.....	73	18.5	20.3	12.7	Fire; healed.
159.....	76	23.0	21	—	Lightning.
111.....	78	12.4	21.3	—	Very little lightning.
134.....	80	31.4	23	—	Do.
139.....	81	45.5	24	—	Several scars.
138.....	82	29.9	24.1	—	Lightning (?).
89.....	84	44.4	24.6	—	No wounds.
125.....	84	8.9	24.6	82.8	Fire, open; lightning.
130.....	84	25.6	24.6	—	Little lightning.
133.....	85	7.5	25	—	No wounds.
137.....	86	33.7	26	—	Little lightning.
144.....	86	6.3	26	Negligible.	Frost ridge.
146.....	86	22.8	26	—	No wounds.
148.....	87	13.3	26.5	—	Lightning.
149.....	87	27.1	26.5	—	Very little lightning.
124.....	87	6.8	26.5	82	Lightning with fire.
129.....	87	9.6	26.5	—	Fire; healed.
88.....	90	30.1	29	19.9	Fire, healed; lightning.
90.....	92	128.1	30	—	No wounds.
128.....	92	10.2	30	—	Very little lightning.
103.....	94	44.8	31	—	Fire, open; lightning.
122.....	96	38.1	32.5	[4.53]	Fire, open.
127.....	96	32.9	32.5	—	No wounds.
76-a ²	96	25.1	32.5	55.3	Fire, open.
76-b ²	96	25.1	32.5	13.5	Lightning.
21.....	101	46.5	37	—	Do.
120.....	102	22.3	38	16.8	Fire, open.
132.....	103	34.2	39	61	Fire; lightning.
46.....	103	35.2	39	—	No wounds.
72-a.....	104	25.5	40	[2.39]	Lightning.
72-b.....	104	25.5	40	71.8	Do.
158.....	104	68.2	40	47.6	Old girdling; lightning.
126.....	105	20.7	41	43.5	Fire, open.
18.....	105	90.3	41	—	No wounds.
20.....	105	32.2	41	—	Do.
45.....	105	58	41	—	Do.
87.....	105	52	41	—	Do.
102.....	106	29	42	46.9	Fire, open.
121.....	106	48.3	42	Traces.	Lightning.
68.....	107	17.0	43	45.5	Falling tree.

¹ The use of brackets ([]) in column 5 indicates superficial decay of sapwood.² The letters a and b indicate two distinct foci of decay in the same tree.

TABLE I.—*Fundamental data on the pathology of the white fir—Continued.*

No. of tree.	Age.	Volume (cubic feet).			Character of wounds.
		For each tree.	Average for trees of same age.	Of rot, including advance rot (percentage of total volume).	
1	2	3	4	5	6
80.....	107	40.6	43	[92.2]	Lightning.
123.....	107	39.6	43	—	Little lightning.
19.....	107	65	43	—	No wounds.
44.....	107	55.0	43	[9.12]	Frost crack.
23.....	108	61.2	44	—	No wounds.
62.....	109	33.8	45	—	Do.
100.....	110	30.0	46	68.5	Fire, open.
22.....	110	47.7	46	—	No wounds.
75.....	110	14.7	46	—	Fire, open.
78.....	110	72.6	46	58.7	Do.
108.....	110	24.8	46	—	Little lightning.
110.....	110	26.8	46	—	Very little lightning.
104.....	111	32.1	47	23.7	Fire, open.
131.....	111	14.6	47	—	Fire; little lightning.
94.....	112	66.2	48	42.9	Twin healed in; frost crack.
99.....	112	40.8	48	42.1	Fire, open; lightning.
37.....	112	40.7	48	51.5	Frost crack.
96.....	113	25.7	49	[23.9]	Fire, open.
101.....	114	30.3	50	—	Fire; lightning.
97.....	116	11.7	52	[Trace.]	Fire, open.
109.....	116	36.3	52	40	Do.
98.....	118	11.5	53.5	—	No wounds.
140.....	118	20.5	53.5	—	(?)
40.....	119	89.5	54	—	Fire.
74.....	119	37.6	54	100	Fire; lightning.
115.....	121	18.9	56	—	Lightning.
150.....	122	46.3	57	—	Little lightning.
58.....	123	39.5	58	89.0	Frost crack.
69.....	123	18.5	58	[8.8]	Lightning.
154.....	123	21.8	58	77	Fire, open.
38.....	124	141	59	29.0	Fire.
56.....	124	21.3	59	60.0	Frost crack; lightning.
113.....	124	30.5	59	Negligible.	Fire, open; lightning.
33.....	125	53.5	61	—	Lightning.
41.....	125	125.5	61	58.1	Fire, open.
60.....	126	42.7	62	82.1	Frost crack.
79.....	129	85.6	65	80.3	Fire, open; frost crack.
54.....	130	32.8	66	77.5	Lightning.
63.....	130	52.3	66	32.4	Fire, open.
65.....	131	14.3	67	93.7	Frost crack.
17.....	132	87.4	69	—	No wounds.
30.....	132	256.5	69	—	Do.
49.....	132	98.2	69	65.3	Frost crack.
42.....	133	90.2	70	34.6	Fire, open.
112.....	133	26.4	70	—	Lightning.
53.....	134	28.8	71	21.8	Do.
28.....	135	55.1	73	42.0	No wounds.
55.....	135	83.2	73	60.7	Fire; frost cracks; lightning.
26.....	136	9.9	74	95.6	Frost crack.
16.....	136	108	74	—	No wounds.
48.....	136	86.4	74	76.9	Do.
1.....	137	49.1	76	—	Do.
50.....	137	33.6	76	85.3	Lightning.
2.....	138	77.4	78	—	Do.
15.....	138	76.3	78	—	Frost crack.
6.....	140	54.4	80	96.4	Fire.
7.....	140	187.0	80	—	No wounds.
70.....	140	20.6	80	132.7	Lightning.
119.....	140	24.3	80	100	Lightning, severe.
153.....	140	50.4	80	—	Lightning.
155.....	140	28.2	80	00	Fire, open; lightning.
43.....	140	136.5	80	133.5	Fire, open.
156.....	141	51.1	82	00	Do.
61.....	143	35.0	86	51.2	Falling tree; frost crack; lightning.
11.....	144	235.5	87	—	No wounds.
4.....	146	94.5	90	[27.7]	Fire.
106.....	146	30.0	90	88]	Frost crack; lightning.
5.....	148	135.5	94	70]	Frost crack.
35.....	148	154	94	—	No wounds.
92.....	149	34.1	96	60.1	Fire, open.
10.....	150	66.5	97	—	No wounds.

TABLE I.—*Fundamental data on the pathology of the white fir—Continued.*

No. of tree.	Age.	Volume (cubic feet).			Character of wounds.
		For each tree.	Average for trees of same age.	Of rot, including advance rot (percentage of total volume).	
1	2	3	4	5	6
25.....	150	123.5	97	81.5	Frost crack.
114.....	150	45.6	97	55.5	Fire, open; lightning.
157.....	150	112.5	97	68	Do.
151.....	151	16.6	99	41.3	(?)
85.....	152	192.5	101	58.1	Frost crack.
9.....	152	75	101	15.7	Do.
13.....	155	235	107	63.2	Fire, open.
31.....	155	121	107	36.2	Do.
117.....	155	37.7	107	Negligible.	Lightning.
83.....	156	380	109	36.5	Fire; frost crack.
91.....	156	96.5	109	32.8	Do.
27.....	159	152.0	109	—	No wounds.
12.....	160	224.5	116	73.7	Fire, open.
93.....	160	26.8	116	98.5	Fire, open; lightning.
118.....	161	68.6	118	—	Lightning.
160.....	161	68.2	118	89.4	Frost crack.
116.....	162	38	121	—	Lightning.
47.....	163	122.5	123	—	Notes missing.
81.....	163	106	123	82.9	Fire, open.
84.....	164	417	125	25.5	Frost crack (healed); lightning.
3.....	165	(?)	127	Incomplete.	Fire, open.
51.....	165	128.5	127	53.4	Fire; lightning.
24.....	166	57.2	129	(?)	Notes missing.
32.....	166	171.5	129	—	No wounds.
29.....	168	179	134	—	Fire.
82.....	169	291.7	136	6.8	Fire; frost cracks.
8.....	170	328.5	138	53	Fire.
57.....	170	121	138	87.4	Frost crack.
67.....	170	123.8	138	67.2	No wounds.
64-a.....	175	68.0	150	47.1	Fire, open.
64-b.....	175	68.0	150	16.4	Lightning.
36.....	178	212.7	158	—	Frost crack.
52.....	178	127.7	158	[5.1]	Lightning.
77.....	180	133	164	16.7	Fire, open.
71.....	183	100	[166]	39.5	Lightning.
34.....	185	148.3	[166]	—	No wounds.
95.....	185	100.5	[166]	53.6	Fire, open.
107.....	186	42.85	[166]	—	Lightning.
66.....	189	64.4	[168]	—	Frost ridge; lightning.
39.....	191	546	[168]	52	Fire.
86.....	192	110.7	[170]	95.5	Fire, open; frost cracks.
14.....	200	115.7	[180]	Negligible.	Frost crack.
142.....	200	26.0	[180]	100	Fire, open; lightning.
73.....	221	196	[190]	100	Frost crack; lightning.
59.....	232	235	[200]	71.3	Lightning.
141.....	258	46.7	[220]	[100]	Fire, open; frost cracks; lightning.

These volumes are, of course, not directly comparable with each other; they have a meaning only when individually compared with normal volumes for the same age. It was necessary, therefore, to curve data collected on normal trees, such as were selected for volume tables in larger numbers on the same area. The most reliable portion of this curve lies between 80 and 180 years. The relation of the actual to the average volume of trees of the same age we may use as an index of suppression or dominance of the individuals in question.

The volume of the decayed part of the bole was figured as the affected part of the cone. But instead of giving the decay simply in

cubic feet, making constant reference to the total volume of the tree necessary, the volume of the rot was expressed in percentage of the total volume. Advance rot—that part of the wood already under the influence of the mycelium—is included. It must be kept in mind that all figures given under this heading (column 5) are therefore likely to be high. To be on the conservative side, all measures of decay were taken very carefully, and in all cases where there was any possible doubt the uncertain part was measured as decay. But since the same procedure was followed consistently the results are directly comparable.

Table I gives us our working material in figures. Column 1 shows the individual number of each tree from the field notes and is given only for convenience of reference, the trees being arranged in the order of their ages (column 2). Column 3 shows the actual or total volume in cubic feet of each tree, considered as a perfect cone. Column 4 gives the volume in cubic feet for the average tree of the same age. Column 5 shows the volume of rot (including advance rot) in cubic feet expressed as a percentage of the total volume of the tree. Column 6 shows the character of the wounds.

CONDENSATION OF DATA.

It proved difficult to interpret intelligently this mass of figures. If there existed any relation between decay and possible influencing factors, it certainly did not appear very clearly from this table. It became necessary to simplify and condense the material.

Instead of expressing dominance or suppression by the relation of the actual to the normal volume in figures, the system of crosses described above for the field notes was used. Three classes were adopted—dominant, intermediate, and suppressed. Those volumes which came closest to the average were considered intermediate and entered in the table with one cross, which expresses the affirmative; a dash signifies negation. In the intermediate class therefore there can be not more than one cross. The deviation from this average shows in the two other classes, and as here all degrees are possible, the degree of suppression or of dominance is shown with one, two, or three crosses. Thus, three crosses under "Dominance" mean that the tree is as far beyond the average as is possible in that locality. On the other hand, one cross under "Suppression" means that the tree is decidedly suppressed, two crosses that it is badly suppressed, and three crosses indicate the highest degree of suppression. This classification is admittedly arbitrary; it seemed to answer the purpose, however, and has so many advantages, with its possible grades and its graphical clearness, that it may be retained until some better method is devised. (Table II, columns 3, 4, and 5.)

To reduce the figures in column 5 of Table I to simpler symbols was more difficult. Here the entire affected part of the cone for practical purposes was considered as cull, including the sapwood. In reality, there are, of course, all gradations from a slight discoloration of the sapwood following a long lightning scar or a number of smaller scars to complete destruction of the heartwood by decay. In order to simplify this column and to bring out more forcibly its relation to influencing factors, the writer tried to reduce the percentage figures to ratings, applying the system of crosses used throughout this study, taking into account not only the volume percentage of rot in cubic feet, but also the character of the injury with regard to the degree of rottenness. Thus, one cross in parentheses, (x), signifies slight and negligible local discoloration; one cross (not in parentheses) shows distinct rot, but affecting not more than about one-third of the tree; two crosses, about two-thirds of tree affected; three crosses, more or less of the entire tree affected. In each case, the character of the decay as indicated by the detailed field notes was given due consideration. This explains apparent discrepancies between decay rating and decay volume in the percentages in Table I, where the affected part of the bole was considered as cull for the entire length of the decay. In decay rating, the actual loss in merchantability was expressed according to the character of the rot and its extent. This valuation of the decay, it is true, is necessarily somewhat arbitrary. It is really the condensation of carefully taken field notes and measurements and must serve until a more satisfactory method can be found. Where general relationships only are concerned, as in this case, our symbols may be sufficiently correct, provided they are based on exact figures and reliable field notes. (Table II, column 6.)

In order to insure a higher degree of reliability for the decay-rating symbols, the operation was repeated some time later without consulting the results of the first. With insignificant exceptions, both ratings were identical.

In much the same way the character and degree of wounding was reduced to a system of crosses. Plainly, this can be done only from field notes, which were generally amplified by actual measurements of the size and extent of the wound. The chances of inoculation offered by a wound decide its rating. That deep wounds, particularly such as have remained open for a longer time, are rated higher than small superficial injuries, soon healed over, is self-evident. The system of crosses is the same as heretofore explained. (Table II, column 7.)

The next column (Table II, column 8) indicates the means whereby the fungus entered the tree, as evidenced by the analysis.

TABLE II.—Condensed data on the pathology of the white fir.

No. of tree.	Age.	Degree of dominance or of suppression.			Decay rating.	Wound rating.	Infection traced to—	Apparent condition of crown.	Remarks.
		Dominance.	Intermediate.	Suppression.					
1	2	3	4	5	6	7	8	9	10
136	60	—	—	x	—	xx	Lightning.....	(x)	Negligible; advance rot.
105	69	xx	—	—	.....	(x)	—	(x)	
145	71	—	—	xx		—	—	(x)	Negligible.
135	72	—	—	x	.....	—	—	(x)	
147	72	—	—	xx	.....	—	—	(x)	
143	73	—	—	x	—	xx	Fire.....	(x)	
159	76	—	x	—	.....	x	—	x	
111	78	—	—	xx	.....	—	—	x	
134	80	xx	—	—	.....	—	—	(x)	
139	81	xxx	—	—	.....	xx	—	(x)	
138	82	xx	—	—	.....	x	—	(x)	
89	84	xxx	—	—	.....	—	—	x	
125	84	—	—	xxx	xx	xxx	Fire; lightning.	xxx	Advance rot.
130	84	—	x	—	.....	—	—	(x)	
133	85	—	—	xxx	.....	—	—	x	
137	86	x	—	—	.....	x	—	(x)	
144	86	—	—	xxx	—	xx	Frost crack.....	xxx	
146	86	—	—	x	.....	—	—	(x)	
148	87	—	—	xx	.....	xx	—	(x)	
149	87	—	x	—	.....	—	—	(x)	
124	87	—	—	xxx	x	xxx	Lightning; fire.	xxx	
129	87	—	—	xxx	.....	x	—	x	
88	90	—	x	—	x	xx	Fire.....	x	Advance rot.
90	92	xxx	—	—	.....	—	—	x	
128	92	—	—	xx		—	—	(x)	Negligible.
103	94	x	—	—	.....	xx	—	x	
122	96	x	—	—	—	xx	Fire, open.....	x	Advance rot.
127	96	—	x	—	.....	—	—	x	
76-a	96	—	—	xx	xx	xxx	Fire, open.....	x	Advance rot.
76-b	96	—	—	xx	x	xxx	Lightning.....	x	
21	101	xx	—	—		xx	—	x	Advance rot.
120	102	—	—	xx	—	xxx	Fire, open.....	x	
132	103	—	—	x	xx	xxx	Fire.....	(x)	Advance rot.
46	103	—	—	x	.....	—	—	x	
72-a	104	—	—	xx	—	xxx	Lightning.....	xx	Advance rot.
72-b	104	—	—	xx	x	xxx	do.....	xx	
158	104	xx	—	—	xx	xxx	Girdling.....	(x)	Almost completely girdled 82 years ago; wound open 31 years; mostly advance rot.
126	105	—	—	xx	xx	xxx	Fire, open.....	x	
18	105	xxx	—	—	.....	—	—	x	
20	105	—	—	xx	.....	—	—	x	
45	105	x	—	—	.....	—	—	x	
87	105	x	—	—	.....	—	—	x	
102	106	—	—	xxx	xx	xxx	Fire, open.....	xx	
121	106	—	x	—	.....	xxx	Lightning.....	x	
68	107	—	—	xxx	x	xxx	Falling tree.....	xx	
80	107	—	x	—	x	xx	Lightning.....	x	
123	107	—	—	x		—	—	x	Negligible.
19	107	xx	—	—	.....	—	—	x	
44	107	xx	—	—	—	xx	Frost crack.....	(?)	Negligible.
23	108	xx	—	—	.....	—	—	x	
62	109	—	—	x		—	—	x	Mostly advance rot.
100	110	—	—	xx	x	xxx	Fire, open.....	x	
22	110	—	x	—		—	—	x	Rot following two very long open scars.
75	110	—	—	xxx	.....	xx	—	x	
78	110	xx	—	—	xx	xxx	Fire, open.....	(x)	Advance rot.
108	110	—	—	xxx	.....	—	—	(x)	
110	110	—	—	xxx		—	—	(x)	Advance rot.
104	111	—	—	xx	x	xxx	Fire, open.....	x	
131	111	—	—	xxx		x	—	(x)	Very slight advance rot.
94	112	x	—	—	x	xxx	Twin and frost crack.	x	
99	112	—	—	x	x	xxx	Lightning.....	xx	Slight advance rot.
37	112	—	—	x	x	xxx	Frost crack.....	x	
96	113	—	—	xx	—	xxx	Fire, open.....	x	Little typical rot.
101	114	—	—	xx	.....	x	—	x	

TABLE II.—Condensed data on the pathology of the white fir—Continued.

No. of tree.	Age.	Degree of dominance or of suppression.			Decay rating.	Wound rating.	Infection traced to—	Apparent condition of crown.	Remarks.
		Dominance.	Intermediate.	Suppression.					
1	2	3	4	5	6	7	8	9	10
97	116	—	—	xxx	—	xx	Fire.....	x	Negligible.
109	116	—	—	xx	x	xx	Fire, open.....	x	Mostly advance rot.
98	118	—	—	xxx	—	—	—	x	
140	118	—	—	xxx	—	(x)	—	(x)	
40	119	xx	—	—	—	xx	—	x	
74	119	—	—	xx	x	xxx	Fire (?), with lightning.	x (?)	Advance rot.
115	121	—	—	xxx	—	x	—	x	
150	122	—	—	x	—	—	—	(x)	
58	123	—	—	xx	xx	xx	Frost crack.....	x	Much advance rot.
69	123	—	—	xxx	—	x	Lightning.....	x	Advance rot; negligible.
154	123	—	—	xxx	xx	xxx	Fire, open.....	x	Very long scar.
38	124	xxx	—	—	x	xx	Fire.....	x	Little advance rot.
56	124	—	—	—	x	xx	Frost crack.....	x	Advance rot.
113	124	—	—	xx	—	xx	Fire; lightning..	x	
33	125	—	—	x	—	x	—	x	
41	125	xxx	—	—	xx	xxx	Fire, open.....	x	Much advance rot.
60	126	—	—	xx	xxx	xx	Frost crack.....	x	Sporophore.
79	129	x	—	—	xxx	xxx	Fire, with frost crack.	x	Two very bad burns held open by frost crack for 85 years; sporophore.
54	130	—	—	xxx	xx	xxx	Lightning.....	x	Much advance rot; young sporophore.
63	130	—	—	xx	xx	xxx	Fire, open.....	xx	Very bad open fire scar.
65	131	—	—	xxx	xxx	xx	Frost crack.....	(?)	
17	132	xx	—	—	—	—	—	x	
30	132	xxx	—	—	—	—	—	x	
49	132	xx	—	—	xxx	xx	Frost crack.....	x	Much advance rot; 2 sporophores.
42	133	xx	—	—	x	xxx	Fire, open.....	xx	Mostly advance rot.
112	133	—	—	xxx	—	xx	—	x	
53	134	—	—	xxx	x	x	Twin (?).....	x	Advance rot.
28	135	—	—	xx	x	—	Knots.....	x	Slight advance rot.
55	135	x	—	—	xx	xxx	Fire, with frost crack.	x	Much advance rot.
26	136	—	—	xxx	xxx	xx	Frost crack.....	xxx	Sporophore.
16	136	xx	—	—	—	—	—	x	
48	136	—	x	—	xxx	—	Knots.....	x	Sporophore.
1	137	—	—	xx	—	—	—	x	
50	137	—	—	xxx	xxx	x	Lightning and knots.	x	Much advance rot.
2	138	—	x	—	—	xx	—	x (?)	
15	138	—	x	—	—	x	—	x	
6	140	—	—	xxx	xxx	xx	Fire.....	(?)	Sporophore.
7	140	xxx	—	—	—	—	—	x	
70	140	—	—	xxx	x	xxx	Lightning.....	x	Slight advance rot.
119	140	—	—	xxx	xxx	xxx	do.....	xxx	
153	140	—	—	xx	—	x	—	(x)	
155	140	—	—	xxx	xxx	xxx	Fire, open.....	xxx	
43	140	xx	—	—	x	xxx	do.....	x	Tree almost killed at age of 81 years; mostly advance rot.
156	141	—	—	xxx	xxx	xxx	do.....	x	
61	143	—	—	xxx	xx	xx	Frost crack; wounds from falling tree.	x	Much advance rot near wounds.
11	144	xxx	—	—	—	—	—	x	
4	146	—	x	—	x	xx	Fire.....	x	Advance rot.
106	146	—	—	xxx	xx	xxx	Lightning and frost.	x	Much advance rot in scars.
5	148	xx	—	—	xx	xx	Frost crack.....	x	Small sporophore.
35	148	xxx	—	—	—	—	—	x	
92	149	—	—	xxx	xx	xxx	Fire, open.....	xx	Rot following scars.
10	150	—	—	xx	—	—	—	x	
25	150	xx	—	—	xxx	xxx	Frost crack.....	x	
114	150	—	—	xxx	xx	xxx	Fire, open.....	x	
157	150	x	—	—	xx	xxx	do.....	xx	
151	151	—	—	xxx	xx	xx	(?)	xx	Much advance rot; small tree.

TABLE II.—Condensed data on the pathology of the white fir—Continued.

No. of tree.	Age.	Degree of dominance or of suppression.			Decay rating.	Wound rating.	Infection traced to—	Apparent condition of crown.	Remarks.
		Dominance.	Intermediate.	Suppression.					
1	2	3	4	5	6	7	8	9	10
85	152	xx	—	—	xx	x	Frost crack.....	x	Two sporophores. Scar long healed over.
9	152	—	—	xx	x	xx	do.....	x	
13	155	—	—	xxx	xx	xxx	Fire, open.....	x	Slight advance rot.
31	155	x	—	—	x	xxx	Fire.....	x	
117	155	—	—	xxx	—	xx	Lightning.....	xxx	Much advance rot and shake.
83	156	xxx	—	—	xx	xxx	Frost crack.....	x	
91	156	—	—	x	x	xxx	Fire, open.....	xx	Sporophore.
27	159	xxx	—	—	—	—	—	x	
12	160	xxx	—	—	xxx	xxx	Fire.....	x	
93	160	—	—	xxx	xxx	xxx	Fire, open.....	x	
118	161	—	—	xxx	—	x	—	xxx	
160	161	—	—	xxx	xxx	xxx	Frost crack.....	xxx	
116	162	—	—	xxx	—	x	—	x	
47	163	—	x	—	—	x	—	x	
81	163	—	—	x	xxx	xxx	Fire, open.....	xxx	
84	164	xxx	—	—	xx	xx	Knots.....	x	
3	165	(?)	(?)	(?)	xx	xxx	Fire.....	x	Small sporophore. Notes incomplete; D. B. H. 26.5 inches.
51	165	—	x	—	xx	xx	do.....	x	Much advance rot.
24	166	—	—	xxx	x	(?)	(?)	x	Notes incomplete.
32	166	xx	—	—	—	—	—	x	Very thrifty.
29	168	xx	—	—	—	(x)	—	x	
82	169	xxx	—	—	x	xxx	Knot.....	(x)	
8	170	xxx	—	—	xx	xx	Fire.....	x(?)	
57	170	—	—	x	xxx	xx	Frost crack.....	xx	
67	170	—	—	x	xxx	—	Knot.....	x	
64-a	175	—	—	xxx	xxx	xxx	Fire, open.....	x	
64-b	175	—	—	xxx	xx	xxx	Lightning.....	x	
36	178	xx	—	—	—	x	—	x	
52	178	—	—	x	—	x	Lightning.....	x	Advance rot.
77	180	—	—	xx	x	xxx	Fire.....	x	Advance rot and shake.
71	183	—	—	xx	x	xxx	Lightning.....	xx	Advance rot.
34	185	—	—	x	—	—	—	x	Fire 110 years ago. Large sporophore.
95	185	—	—	xx	xx	xxx	Fire, open.....	x	
107	186	—	—	xxx	—	xx	—	x	
66	189	—	—	xxx	—	xx	—	x	
39	191	xxx	—	—	xx	xxx	Fire.....	x	
86	192	—	—	xx	xxx	xxx	Frost crack.....	x	
14	200	—	—	xx	—	x	do.....	xxx	
142	200	—	—	xxx	xxx	xxx	Fire.....	xxx	
73	221	—	x	—	xxx	xx	Frost crack with lightning.	xx	Four sporophores.
59	232	x	—	—	xxx	x	Lightning.....	(?)	Much advance rot.
141	238	—	—	xxx	xxx	xxx	Fire with frost crack.	xxx	Mostly advance rot with shake.

Another column concerns the apparent condition of the tree (Table II, column 9) and indicates the appearance of health of the crown, taking the healthy, thrifty tree as normal (indicated by one cross) and marking the degree of deviation from the normal in the usual way. Thus, one cross in parentheses, (x), means that the tree is an exceptionally healthy one; two crosses (not in parentheses) indicate that the crown is rather poor, either in development or that the color is abnormal, etc.; and a tree having a very much underdeveloped and sickly looking crown is marked with three crosses. The personal

factor may, of course, lead to misinterpretations unless the same standard is applied throughout the entire study. For this very reason it seemed doubtful from the beginning whether these data would be of much value. They are given here merely for the sake of completeness.

The condensed material was again tabulated. In the condensed table (Table II) the relation of decay to age can easily be followed by comparing columns 2 and 6. "Decay rating" is placed between "Suppression" and "Wound rating" in order to bring out forcibly any possible relation between these factors.

INTERPRETATION.

The column that interests us most is apparently the sixth, "Decay rating." In glancing over this column and comparing it with the neighboring ones we can read directly the connection of decay with factors that may be of influence. Each separate case of decay, of which one, two, or even more can occur on the same tree, may be called, for simplicity's sake, in this study, a "cull case." Each cull case is the result of a separate infection. The actual loss of timber by fire burning out the stump does not concern us here; cull from this source is included in the "volume of rot" whenever the decay is directly traceable to the fire wound. Otherwise the cull from fire is neglected. Cull from knots, limbs, or wind-shake is not considered. Altogether there are 97 cull cases.

The first two cull cases are negligible for practical purposes. Some loss occurs in tree No. 125, 84 years old. We see that this is a very badly suppressed tree, very seriously wounded, in very bad health, and that it is injured by both fire and lightning. Another case occurs in tree No. 124, age 87 years. Again suppression, wounding, and condition of health are marked with three crosses, indicating the worst possible conditions, together with two causes of wounds—fire and lightning. In both cases fire is the more serious, lightning often occurring higher up on the tree in numerous small wounds. It carries advance decay to the upper part of the bole and materially increases the volume-rot figure and the decay rating. The next cull case is a slight one (tree No. 88, age 90 years). The tree is intermediate, wound rating medium, health good, the decay only advance rot. Continuing down the "Decay-rating" column and comparing the symbols with those in the neighboring columns, we find that in almost every case the rating of rot more or less expresses or is explained by the factors of suppression and wound rating. Apparent discrepancies generally find their explanation under "Remarks" (column 10).

Suppression shows at an early age. A distinct preponderance of suppression is noticeable from about the age of 84 years. The first

very pronounced cases appear in the same year. They seem to become particularly common from about 110 to 120 years.

Suppression stands out strongly as an important factor. Out of the total of 97 cull cases, 66 are connected with suppression. Considering that our average volumes over ages were curved from figures which were rather low and that the intermediate white firs in a virgin uneven-aged mixed stand are rather to be considered as recovering suppressed trees than as dominants decreasing in rate of height growth the intermediate class may consistently be added to the suppressed, giving 73 in all, or about 75 per cent. Suppression is commonly connected with a more or less high decay rating, provided the tree is wounded seriously. Again, low-volume trees with marked decay are more liable to be a total loss on account of their form. A rot volume percentage of 50, for instance, leaves still a good deal of merchantable stuff in a tree with high volume, but it would make a small tree completely unmerchantable. In the comparatively few cases where dominant trees show decay, the wounding is either of very momentous character or the decay is more or less insignificant and localized near the scars. This is true at least for the younger trees.

In glancing over the decay column we see that the higher ratings, xx and xxx, begin rather suddenly to become more frequent after the trees have reached the age of about 123 to 126 years; after the age of about 129 or 130 years they become very common. While decay in the broadest sense of the word may show in trees 60 years old and perhaps younger, the critical age of white fir with regard to more serious decay appears to lie at about 130 years, at least for the region investigated, taking into account that we have to deal here with a practically virgin stand grown up under the cumulative risk from suppression, frost, lightning, and the other factors of influence. Decay of any consequence appears at this age in trees with a combination of wounding and suppression. In the few apparent exceptions the decay is localized near unusually large wounds.

We find, further, that up to about 150 (148) years in badly wounded but dominant thrifty trees the decay is either not very far advanced in degree, if in extent, or that the wounding is of quite extraordinarily severe character.

Tree No. 49, age 132, seems to form an exception, but we will see later that frost cracks, though not offering a large opening by virtue of their length, are instrumental in the longitudinal advance of the decay. It seems that after about 150 years thriftiness as expressed by dominance is less able to outbalance the influence of serious wounding.

If it is at all permissible to draw any inference from the comparatively small amount of material at hand, we may distinguish three critical stages in the life history of wounded white-fir trees, and we

must remember that by far the greater number of our trees, especially after they have reached the age of about 80 to 90 years, are wounded.

The first is the "age of infection," which may be at 60 years or below. Here the infection rarely leads to more than negligible decay unless the tree is handicapped by quite unusually severe conditions, such as very large old wounds.

The second, at about 130 years, which we may term the "critical age," marks the point after which a combination of pronounced suppression and heavy wounding generally results in distinct decay. This combination of deleterious factors is one commonly found in virgin forests. Wounding alone is not sufficient to unfavorably counteract thriftiness of growth.

Another change comes about at 150 years, when even dominant (that is, thrifty) trees become subject to extensive and intensive decay. We might term this the "age of decline," because the inability of the individual to throw off or keep in check the growth of the wound parasite in its heartwood indicates a distinct decrease in resistive powers, whatever their specific action may be, induced by age. For thrifty but wounded white fir, such as we may expect to raise under management, the age of decline is, therefore, the factor which will influence the rotation and cutting cycles of the species, since for many years to come the risk of inoculation will be more or less the same. There will be fires as long as there are lightning storms. Wounding through lightning and frost are inevitable. Besides, many trees are already wounded.

It is of interest to note that of a total of 160 trees only about 25 per cent did not show any wounds except very slight lightning scars. All the rest were wounded from some cause or other. Often a combination of fire, lightning, and frost cracks results in scarring a tree to such an extent that almost in every foot some blemish will be found. This is particularly true of the older trees which have been exposed to the cumulative risk of many years. Any of these wounds, if large enough, may offer an entrance to fungi. After the trees have reached the age of about 80 to 90 years, more than 70 per cent of them are already more or less badly wounded and therefore exposed to inoculation. After they are about 106 years of age more than 80 per cent are wounded.

In the remote future, when all these wounded trees are removed and when the risk of wounding for the trees growing up meantime is minimized, a new age of decline may be established. What this age of decline might be for unwounded white fir in managed forests we can not tell from our material, because of 97 cases of decay only 6 were not to be traced to some wounding. It is obviously out of the question to take even a clue from data of so scanty a nature. It may simply be mentioned that the first case of this kind appears at

an age of 134 years in a suppressed tree. After all, it may be more than a coincidence that the first case of such infection in a suppressed tree occurs near the critical age for suppressed white firs in this region. It is within reason to assume that thrifty, uninjured white firs run only the evidently not very great risk of becoming infected through branch stubs. But decay entering through knots is always caused by fungi of a very aggressive character, such as *Echinodontium tinctorium*, which is not always the case with wounds. As a possible cause of infection we may also mention dead and broken-off leaders or volunteers, the stubs of which are only slowly overgrown.

It would appear that, if infections of unwounded trees are really so rare, white fir will take care of itself on the managed areas of the future. This would probably be the case in an ideal, 100 per cent normal forest. But this is utopian. There will always be a certain risk of wounding. Even after the already wounded individuals are eliminated, which will consume a number of decades, it is unreasonable to expect that our forests should then be so much closer to the normal than the best kept European forests are at the present day. How severe the loss from *Trametes pini* in the Prussian forests has already been shown. Whatever may be the final verdict as to the age of decline of unwounded thrifty trees in managed forests, it can not be of more than purely theoretical interest to us and the next following generations. We must cope with present-day conditions as we find them, not as we would wish to have them.

The immense importance of fire in connection with decay appears so plainly from Table II that it is hardly necessary to emphasize the fact. The field notes show that in 59 trees wounded by fire, in only 11 was no decay traced to the fire wound. Fire, then, is one of the most important factors in connection with decay; all the more so, as fire generally attacks the butt part of the tree, and decay starting from fire wounds therefore destroys a much greater part of valuable timber than decay in the upper part of the bole.

Lightning generally results in comparatively light advance rot. From Table II it appears that the only tree in which serious decay could be traced to lightning, and in which it was neither connected with suppression nor with a serious wound from another source, is No. 59, 232 years old. To judge from our data, lightning is rarely connected with typical decay, although it often renders large parts of the tree partly unmerchantable.

The cumulative risk of wounding is shown in Table II (column 7) by the fact that the cases rated with three crosses become far more frequent after the trees have reached the age of about 90 to 100 years. After they have reached about that age such cases are commonly accompanied by decay. Serious decay follows serious wounding after

about the age of 130 years (critical age) when combined with pronounced suppression, and without this it follows after the age of about 150 years is reached. The risk of wounding increases naturally with the age of the tree.

A number of wounded and badly suppressed trees escape infection, although they are far beyond the critical age. Not every wound must necessarily be inoculated. All such cases found are compiled in Table III.

TABLE III.—Data on suppressed and wounded but not infected white-fir trees.

Age.	Suppression rating.	Wound rating.	Character of wound.	Age.	Suppression rating.	Wound rating.	Character of wound.
87.....	xxx	x	Fire.	140.....	xx	x	Lightning.
110.....	xxx	xx	Do.	161.....	xxx	x	Do.
111.....	xxx	x	Do.	162.....	xxx	x	Do.
121.....	xxx	x	Lightning.	186.....	xxx	xx	Do.
133.....	xxx	xx	Do.	189.....	xxx	xx	Do.

In all cases but one in Table III the degree of suppression is very high; in this case the wound rating is low. The dangerous fire wounds in this table are confined to the youngest ages, 87 to 111 years; they were comparatively small in each case. The rest of the wounds are all due to lightning, which, as will be remembered, does not open up the interior of the tree unless very large parts of the bark are killed. For inoculation and infection, the character of the wound is all important. Suppression has nothing to do with inoculation; only after infection has taken place does its influence make itself felt.

The characteristics of each of the three ages, of course, hold good through the following ages. The combination of wounding with suppression, as shown in the critical age, for instance, must continue to favor decay in the age of decline.

Relative thriftiness (apparent condition of the tree) seems to have the least influence on the decay factor. It is really nothing but a statement of the present temporary appearance of the individual tree, which may be entirely different from what it was a few years ago or what it will be in the near future.

That far-reaching decay must not necessarily be reflected in the appearance and increment of the tree is shown, for instance, by trees Nos. 25 (age 150), 157 (age 150), 85 (age 152), 83 (age 156), and others in Table II. In all the trees mentioned, *Echinodontium tinctorium* had established itself and was vigorously growing. Tree No. 85 (age 152) even had two sporophores, and more than half the volume of the tree was decayed, indicating that the fungus must have lived in the tree for many years. The tree was apparently very thrifty; its volume, 192.5 cubic feet, as against 101, the average for its

age (152 years). The increment was good. We can not, therefore, make *Echinodontium tinctorium* responsible for the decrease in thriftiness of infected white fir.

In order to further fix the relation between the character of the opening through which the fungus gains entrance into the wood and the character and extent of the decay, all cull cases were tabulated separately (Table IV).

TABLE IV.—Cull cases of white fir, showing the extent of typical rot and its relation to the wound through which the infection took place.

No.	Age.	Infection traced to—	Wounds.		Typical rot.		Remarks.
			Open.	In- ternal (healed over).	Confined to neigh- borhood of wounds.	Extend- ing much beyond wounds.	
1	2	3	4	5	6	7	8
136	60	Lightning.....	—	x	x	—	Negligible.
143	73	Fire.....	—	x	x	—	
125	84	Fire with lightning.....	x	—	x	—	
144	86	Frost crack.....	—	x	x	—	Negligible. Advance rot.
124	87	Lightning with fire.....	x	—	x	—	
88	90	Fire.....	—	x	x	—	
122	96	do.....	x	—	x	—	Advance rot.
76a	96	do.....	x	—	—	(x)	
76b	96	Lightning.....	x	—	—	—	
120	102	Fire.....	x	—	x	—	Remained open 22 years.
132	103	do.....	—	x	—	(x)	
72a	104	Lightning.....	—	x	x	—	
72b	104	do.....	—	x	x	—	Almost completely girdled 82 years ago; open 31 years.
158	104	Girdling.....	—	x	x	—	
126	105	Fire.....	x	—	x	—	
102	106	do.....	x	—	x	—	Negligible.
121	106	Lightning.....	x	x	x	—	
68	107	Wound from falling tree.....	x	—	x	—	
80	107	Lightning.....	—	x	x	—	Frost.
44	107	Frost crack.....	x	—	x	—	
100	110	Fire.....	x	—	x	—	
78	110	do.....	x	—	x	—	Frost.
104	111	do.....	x	—	x	—	
94	112	Twin and frost crack.....	—	x	x	—	
99	112	Lightning.....	—	x	x	—	Frost.
37	112	Frost crack.....	—	x	(?)	—	
96	113	Fire.....	x	—	x	—	
97	116	do.....	x	—	x	—	Frost.
109	116	do.....	x	—	x	—	
74a	119	Fire (?).....	—	x	x	—	
74b	119	Lightning.....	x	—	x	—	Frost.
58	123	Frost crack.....	—	x	—	x	
69	123	Lightning.....	—	x	x	—	
154	123	Fire.....	x	—	x	—	Advance rot.
38	124	do.....	—	x	x	—	
56	124	Frost crack.....	x	—	—	—	
113	124	Fire with lightning.....	x	—	x	—	Frost. Do.
41	125	Fire.....	x	—	x	—	
60	126	Frost crack.....	—	x	—	x	
79	129	Fire with frost crack.....	x	—	—	x	Frost. Do.
54	130	Lightning.....	—	x	x	—	
63	130	Fire.....	x	—	x	—	
65	131	Frost crack.....	—	x	—	x	Frost. Do.
49	132	do.....	—	x	—	x	
42	133	Fire.....	x	—	x	—	
53	134	Twin(?).....	—	(?)	x	—	Knots. Frost.
28	135	Knots.....	—	—	—	x	
55	135	Fire with frost crack.....	—	x	—	x	
26	136	Frost crack.....	x	—	—	x	Knots(?). Much advance rot. Sporophore.
48	136	Knots.....	—	—	—	x	
50	137	Lightning and knots.....	—	x	—	x	
6	140	Fire.....	(?)	(?)	—	x	Sporophore.
70	140	Lightning.....	—	x	x	—	
119	140	do.....	x	—	x	—	

TABLE IV.—*Cull cases of white fir, showing the extent of typical rot and its relation to the wound through which the infection took place—Continued.*

No.	Age.	Infection traced to—	Wounds.		Typical rot.		Remarks.
			Open.	Internal (healed over).	Confined to neighborhood of wounds.	Extending much beyond wounds.	
1	2	3	4	5	6	7	8
155	140	Fire.....	x	—	—	x	Condition very poor; suppression xxx.
43	140	do.....	x	—	x	—	
156	141	do.....	x	—	x	—	
61a	143	Frost crack.....	—	x	—	x	Frost.
61b	143	Falling tree.....	—	x	x	—	Advance rot.
4	146	Fire.....	(?)	(?)	(?)	(?)	Notes incomplete.
106	146	Lightning and frost.....	x	—	x	—	Advance rot.
5	148	Frost crack.....	—	x	—	x	Frost.
92	149	Fire.....	x	—	x	—	
25	150	Frost crack.....	x	—	—	x	Frost.
114	150	Fire.....	x	—	—	x	Butt open from fire 73 years ago; suppression xxx.
157	150	do.....	x	—	x	—	
151	151	(?).....	—	x	x	—	
85	152	Frost crack.....	—	x	—	x	Frost.
9	152	do.....	—	x	x	—	
13	155	Fire.....	x	—	—	x	
31	155	do.....	x	—	x	—	
117	155	Lightning.....	—	x	x	—	
83	156	Frost crack.....	—	x	—	x	Frost.
91	156	Fire.....	x	—	x	—	
12	160	do.....	x	—	—	x	
93	160	do.....	x	—	—	x	Suppression xxx.
160	161	Frost crack.....	x	—	—	x	Frost.
81	163	Fire.....	x	—	—	x	Condition very poor; suppression x.
84	164	Knots.....	—	—	—	x	Knots.
3	165	Fire.....	x	—	—	x	
51	165	do.....	—	x	—	x	
24	166	(?).....	(?)	(?)	(?)	(?)	Notes incomplete.
82	169	Knot.....	—	—	—	x	Knot.
8	170	Fire.....	(?)	(?)	—	x	
57	170	Frost crack.....	—	x	—	x	Frost.
67	170	Knot.....	—	—	—	x	Knot.
64a	175	Fire.....	x	—	—	x	Suppression xxx.
64b	175	Lightning.....	—	x	x	—	
52	178	do.....	—	x	x	—	Advance rot.
77	180	Fire.....	x	—	x	—	
71	183	Lightning.....	—	x	x	—	
95	185	Fire.....	x	—	—	x	Suppression xx.
39	191	do.....	x	—	—	x	Dominance xxx; fire 110 years ago; deep burn.
86	192	Frost crack.....	—	x	—	x	Frost.
14	200	do.....	—	x	x	—	
142	200	Fire.....	x	—	—	x	Condition very poor; suppression xxx.
73a	221	Frost crack.....	—	x	—	x	Frost.
73b	221	Lightning.....	x	—	x	—	
59	232	do.....	—	x	—	x	
141	258	Fire with frost crack....	x	—	x	—	Advance rot.

Table IV is designed to show whether and in which cases typical rot extends much beyond the wounds forming the entrance for the fungus. Column 7 is the one to be followed ("Typical rot, extending much beyond wounds"). The affirmative is expressed by a cross, x, the negative by a dash, —. Cases which are on the line between the two are marked by a cross in parentheses; they are negligible for our purposes. The first tree to be considered, No. 58, is 123 years old and has a frost crack. From this age, or rather after 126 to 130

years, these cases become more and more frequent. In most cases, to judge from this table, frost cracks are a strong factor for extending typical decay much beyond the point of entrance of the fungus. By splitting the bole for a considerable length they allow air to enter the wood, which evidently stimulates the growth of the fungus.

In noting the cases of decay traced to the wounds or openings through which the fungus found its entrance, it is seen that two and even more cases of decay (cull cases) may be found on the same tree, but each case is counted separately. Where decay is traced to a combination of two factors, each factor is shown separately. The means of entrance of the fungus causing decay are thus shown to be as follows: Fire, 48; frost, 25; lightning, 23; other causes (including knots, girdling, etc.), 13; total, 109.

These 109 wounds (including knots, etc.) led to 97 cull cases. Out of 109, only 13 were other than wounds from fire, frost, and lightning, and 11 of the 109 cases of decay were the effect of a combination of two of the causes named. Fire has by far the greater share; frost and lightning are second, but the preponderance of fire and frost over lightning is greater than would appear, since they are far more serious with respect to causing decay. If ratings are given, more or less arbitrarily, but yet in keeping with our field observations, to the various causes of wounds in the order of their importance with relation to damaging decay in white fir, taking injury from lightning (the least consequential) as the unit, we have: Fire, 3; frost, 4; lightning, 1; other causes (including knots, girdling, etc.), 3. Then, multiplying the figures for means of entrance by these relative ratings we have: Fire, 144; frost, 100; lightning, 23; other causes, 39. These figures express the following facts: (1) Fire injury is not only numerically the strongest, but also commonly leads to considerable cull; (2) frost damage is less frequent (above all, less ubiquitous) than fire damage, because it appears only in typical frost belts or frost holes, but it carries decay over a much greater length of the bole; (3) lightning injury is fairly common, is also restricted to certain belts, and leads more often to superficial rot; (4) other factors are of importance as causes of damaging decay, but they are comparatively rare.

CONCLUSIONS AND OUTLOOK.

The interpretation of the results of this study of the white fir from a practical point of view can not leave out of consideration the fact that the basis for all computations and tables is a comparatively small one and that the actual figures and many of the principles derived therefrom have more the value of strong indications for local application than the force of general laws. Still quite a number of the considerations will be directly applicable, at least in all similar types, some throughout the range of white fir. The writer would emphasize again that the aim of the present study is not to lay down laws, but

to show by means of one example the problems before us and the various steps leading up to a working method for the future establishment of laws which may—or may not—confirm the conclusions from this study, and to strongly advocate similar studies on a larger scale. With this point plainly in view, but assuming that our conclusions are a step in the right direction, we may discuss their bearing on the silvicultural problems that are before us.

DECAY IN RELATION TO WOUNDS.

In most cases, decay in white fir is caused by *Echinodontium tinctorium*. The mycelium never enters through the intact bark. Fire wounds offer the most common way of entrance; hence, in the majority of cases, decay starts in the butt; frost is less common than fire, but favors the vertical spreading of typical decay. Localized and superficial advance rot, frequently leaving enough merchantable timber in the log to make it worth while handling except when occurring in the upper part of the bole, is often connected with lightning. Other means of entrance, such as knots, wounds from falling trees, and girdling by rodents are comparatively rare.

These factors group themselves naturally into such as are uncontrollable and such as may be controlled directly or indirectly. The entrance of decay through knots, wounds from trees and limbs thrown in heavy storms, or from excessive snowfall lies beyond our control. Injury from mammals as a starting point of decay is very rare and will become even more so with the decrease of the forest fauna.

The other factors are more or less open to influence. Fire is distinctly a directly controllable factor. Lightning and frost are, of course, not directly controllable. It is a fact, however, that both do not occur to any damaging extent except in more or less well-defined belts, and generally more heavily in foci inside of these belts. The natural inference would be not to favor white fir in such belts when possible. As a first step in this direction the establishment and mapping of frost belts, frost holes, lightning zones, and lightning foci would be of particular value, which should not be confined to white fir alone. Other forest trees are also more or less subject to injury from both factors. The value of such maps should also make itself felt in forest-fire control, for the proper distribution of protective forces and improvements.

FOREST REGULATION.

CARE OF VIRGIN FORESTS.

It has been heretofore pointed out that practically the only means of silviculturally influencing the national forests on a larger scale at the disposal of the administration at the present time lies in the handling of timber-sales areas. On all the vast forests outside of these

comparatively restricted areas the same beneficial and injurious conditions must continue to prevail, which on one hand govern the annual increment and on the other make for annual total loss. Only one single component of the total-loss factor, though a most important one, may be controlled to a certain degree directly. Forest fires are in ever-increasing ratio eliminated from the national forests and, therewith, also the danger of trees being fire scarred and opened to the attacks of heartwood-destroying fungi. But the best of fire protection can not restore to their original state of intactness the overwhelmingly large number of older trees which have been opened by previous fires. The open fire wounds continue to offer an easy entrance to fungi. It is true that fire protection prevents small wounds from becoming larger and keeps healing wounds from being opened again by repeated fires. The sooner such fire-wounded trees, as well as all other undesirable individuals, including all badly injured, diseased, and misshapen ones, can be eliminated from the forest, the better. There is little hope, however, for this to be done outside of timber sales. Adequate fire protection, both of watersheds and of commercial timber, must of necessity be paramount to silvicultural work of this kind.

Practically virgin forests may also be influenced by sowing and planting. This is done on so small a scale, compared to the total of existing forests, that we can hardly speak of any real silvicultural change. Knowing, however, that white fir can not be expected to yield full returns in belts subject to lightning and severe frosts, the forester should avoid favoring white fir in such localities.

FOREST REGULATION THROUGH TIMBER SALES.

Cutting timber does not in itself constitute sound silviculture. It may lead to regulation, or it may spell ruin to the forest.

The administration of the national forests is not able to have timber cut by selling it where cutting is most needed. Accessibility, local demand, and last, not least, the quality and condition of the timber are stronger factors in finally locating a timber-sales area than silvicultural needs. A strong admixture of inferior species in itself is often sufficient to let an otherwise attractive sale fall through. Here, the prejudice of the purchaser against such species as white fir and incense cedar is responsible for forcing the Forest Service to leave an area badly in need of improvement in its virgin state, with all the cumulative risk to which it is exposed. The prejudice against white fir is widely established and not always confined to the lumberman.

From a silvical point of view the prejudice is directed against its very aggressiveness, which tends to give the species an ascendancy over the more valuable but less tolerant pines. But the disfavor in which it is held by the forester is really nothing but a reflection of

the strong objection made by the purchasing lumberman to accepting white fir in Government timber sales, and this is based mainly upon the unsoundness of the timber. At the same time, there is a fair local demand for sound white fir for a number of uses. There is no valid objection to clear and sound white fir. In fact, many a purchaser would rather pay higher stumpage for white fir if he were allowed to take only sound young stuff, which is in demand for dimension stuff (2 by 4, 4 by 4, etc.), for frame stuff, timbers, and stickers, and for butter boxes, etc. Purchasers complain that much of the material, though seemingly sound, "has no life" after going through the mill; it becomes brittle and falls to pieces when dry. Sound white fir neither becomes brittle nor does it fall to pieces. It is the unsound material (advance rot) only which is objectionable. The remedy is easily seen; it consists in liberal and judicious scaling, which would rather give the purchaser the benefit of the doubt. The scaler will find valuable aid in the occurrence of decayed knots on the boles of trees affected with stringy brown-rot. To the casual observer they may appear normal; when they are knocked off with a hatchet or similar instrument the decayed rusty interior is exposed. These "rusty knots" afford, in the vast majority of cases, a valuable indication of more or less far-gone *Echinodontium* rot in the heartwood of white fir. Occasionally, the rusty color is missing, but the center of the knot is unmistakably decayed. The verdict as to the rottenness of the heartwood will be the same. The knots are often very small. When sound, they are very brittle and glassy in appearance. To give a practical example:

No. 82 on the Otter & Burns tract, a very fine tree with a long clear bole, 29.4 inches diameter breast high, and 154 feet high, had been given a full scale. The bole had been bucked into 16-foot logs. To the scaler there were no indications of decay. After examining the tree the writer threw out log 5. The only indication for spotting *Echinodontium* decay in this log was the presence of the rusty knot. The log was opened and found to be unmerchantable from 0.5 to 5.6 feet from the lower end, leaving as merchantable 0.5 foot on one end (diameter 19.5 inches) and about 10 feet on the other end (upper diameter 16.3 inches). Had the defect been known to the bucking crew a more advantageous dividing up of the bole in log lengths to the exclusion of the decay would have meant a saving to the operator.

Among others, Bryant¹ has pointed out the necessity of more judicious bucking and of closer utilization.

¹ Bryant, R. C. Waste in cutting timber. *In Amer. Forest.*, v. 19, no. 11, pp. 790-799, 7 figs., 1913.

MARKING.

The entire silvicultural results obtainable by way of timber sales are directly dependent upon proper marking, the importance of which can not be overemphasized. Marking is by far the most portentous of all silvicultural activities and requires a very specific training, of which a complete knowledge of all components of the total-loss factor must be a prominent part.

Marking in the selection forest has a threefold object—to select trees to be cut and utilized at once, to leave others as a basis for future cuttings, and to establish desirable reproduction. Here the interests of the Government as timber owner and timber producer frequently conflict with those of the purchaser. The purchaser can not be expected to take a strong interest in the future of the area he is to cut over. He quite naturally wants as much sound merchantable timber from a given stand as possible. The larger the amount of timber he can cut from an area the smaller the overhead charges will be per thousand feet, board measure. In offering white fir for sale it is, therefore, important to be able to estimate more or less correctly the amount of sound timber on a given tract. If our figures prove correct, the loss factor in white-fir trees will be comparatively small up to an age of about 130 years; after trees with a combination of wounding and suppression have reached the age of 130 years they are liable to contain decay; after they have reached the age of 150 years wounding alone, even in dominant trees, is liable to lead to damaging decay. That trees with sporophores are decayed, at least partly, is self-evident. The actual cull per cent from decay is at present only guessed at. It is the constant aim of forest pathology to reduce this guesswork to actual and concrete figures. It is intended to repeat similar studies throughout the range of white fir and later also on other species in the order of their importance and finally to establish broad zones of equal pathological conditions, in which the rot percentage may be given in definite figures.

Marking can only be done correctly if the outcome of the marking with regard to the trees left standing is constantly kept in mind. In our specific case, for instance, white fir on typical lightning and frost belts should be marked very heavily. We know that here the loss from decay, particularly following frost cracks, is heavy and will grow through cumulative risk. White firs with serious wounds, especially with partly open fire wounds, must be marked heavily to as low a diameter as practicable.

On the other hand, thrifty unwounded trees, where desirable, may be left without much risk up to the age of about 150 years, and probably much longer.

The effect of logging on the pathological condition of white firs that are left on the area may be twofold. The opening of the crown cover through cutting will prove beneficial to all suppressed and intermediate white firs. The ready response of the species to light is well known. It is probable that such trees, if already infected, will not allow the decay to proceed very much farther, i. e., the newly formed upper logs may be sound. These trees move up into the dominant class. The mycelium in the heartwood, however, if well established, will not die out, and after a while sporophores appear which carry the disease to hitherto sound trees. As there can not be any infection except through spores coming from sporophores on diseased trees, it is evident that it is poor silviculture to leave individuals infected with any parasite of economic importance on cut-over areas. Such trees on timber-sale areas should be marked and cut under all circumstances if we expect to save and utilize the sound timber they may contain and to protect other trees from decay. Sanitation of the forest must be the first and fundamental step in forest regulation. The introduction of the so-called sanitation clause in the timber-sale contracts of the Forest Service aims at this very point.

It is evident that blind enforcement of the sanitation clause, following the letter and not the spirit of the principle expressed, is just as pernicious as laxity in its application. Not all parasites are of equal importance; our efforts should first be concentrated on the most dangerous ones. The time will come when forest sanitation will include all controllable elements making for loss in timber volume and timber values.

On the other hand, if only thrifty trees are left standing after logging operations, they are, by the very opening of the "forest screen," more exposed to flying spores from surrounding untreated tracts, but unless wounded they are in no great danger of infection. The smaller the tract, the more will this influence make itself felt. The improved conditions under which they grow will help them to either overcome or limit the extent of decay in case they do become infected. As long as we do not possess any exact figures on the recovery of white fir on cut-over areas, however, it is advisable to consider wounded white-fir trees left standing as unaffected by the opening up of the stand, at least during the transition period, that is, in first fellings. All these trees have grown up under unfavorable conditions, and the chances that they are lastingly injured are considerable. By the time second logging operations cover the area, it is to be assumed that a more profound knowledge of the life history of white fir will be at hand.

The choice of white-fir trees to be left on the area, with the expectation that they will be sound and merchantable at the next felling, depends altogether on their condition and the length of time probably elapsing until that felling takes place. Assuming that our figures

are correct and that the next cutting may occur, for example, in 30 years, we may with comparatively small risk leave thrifty unwounded trees of any age on the area; wounded but thrifty trees of more than 120 years are to be cut, wherever practicable, because in 30 years they will be over 150 years old, at which age trees of this class are more liable to deteriorate. Wounded trees which at the same time are suppressed should be eliminated. It is bad silviculture to leave individuals in the forest which not only do not produce the maximum of timber but which in all probability will prove a total loss and which occupy the place that should be fully stocked with trees promising a full and sound crop. In case of an emergency, such as occurs under very unfavorable market conditions or where the protection of young stuff is the most important feature, wounded and suppressed white firs left standing should not be older than 100 years, since in 30 years they will have reached their critical age—that is, 130 years. After they have reached this age it appears that damaging decay becomes prevalent in trees of this description. Very severely injured trees have, of course, no place in the managed forest. The same is true for unusually suppressed or unhealthy trees, unless it may be expected with reasonable certainty that the opening of the crown cover will benefit them materially. Trees with open fire scars and with open frost cracks should be cut in preference to those with lightning scars or those having wounds from falling neighbors. In short, all wounds reaching far into the wood are to be given a higher rating with respect to decay than superficial wounds unless the latter are unusually large.

PATHOLOGICAL ROTATION AND CUTTING CYCLES.

Since we may expect that cutting during the period of transition will practically eliminate all those trees which by their combination of suppression and wounding become subject to early decay (critical age), the age of decline forms the basis for what might be termed the “pathological rotation,” for want of a better expression. It does not indicate that a given species should most advantageously be cut in regular intervals expressed by the pathological-rotation age, but that it should not be cut at a higher age. It is really a factor limiting the rotation and therefore also the cutting cycle.

Rotation based on maximum volume alone can not be more than a makeshift during the transition period; logically it should be narrowed down to maximum-volume production of sound timber. Such species as *Sequoia gigantea* and *Sequoia sempervirens* are so resistant to decay that their pathology will not influence their rotation at all. In some of our valuable pines the pathological rotation will probably be very high, either coinciding with or reaching beyond the age of maximum-volume production. In white fir, incense cedar, and a

number of other so-called inferior species, the pathological-rotation age is presumably lower than the age of maximum-volume production. We must look to forest mensuration for final data to settle this point.

Barrington Moore¹ advocates a rotation based on the "period during which the rate of volume production is greatest or shortly after it, provided it is long enough to give the most valuable product."² Here, again, the pathological rotation will be the limiting factor, except for species in which the rate of greatest volume production possibly occurs at a lower age than the pathological rotation. That the value of lumber grades is bound to play a far more important rôle in the future than at present, with regard to rotation, is a foregone conclusion.

So far, we have considered only the rotation per species. In pure or almost pure stands the rotation of the unit is determined by the rotation of the species clearly dominating, not only numerically, but also in value.

As soon as two or more equally valuable commercial species appear together in about the same proportion, the rotation of the stand becomes "synthetic;" that is, the rotation for the unit is governed by the individual rotations per species. In the great majority of cases neither the representation of the species nor their individual values are the same. Nearly always there will be certain species more desirable than others, which latter then are classed as more or less inferior. A weak representation of inferior species with low pathological rotation will be without much effect upon the synthetic rotation of the unit. The stronger the representation of inferior species, the heavier will be their bearing on the synthetic rotation.

On many of the large private holdings of the West the inferior species are disregarded altogether; they are simply left standing in logging operations. Unless the logged-over area is burned, the representation of inferior species is then an unduly heavy one. They must necessarily dominate the stand in the future.

The national forests, on the other hand, will be the regulated forests of the future. In many of the national forests, particularly in the West, several species of unequal value are represented on the same unit in such a manner as to make each one a strong factor to be considered. Here, regulation of yield must be based upon synthetic rotation and synthetic cutting cycles. Rotation and cutting cycles for each species must be determined separately, each on the chosen basis of either maximum-volume production, or rate of maximum-volume production, or production of maximum value, limited in

¹ Moore, Barrington. Chapman's method of studying yield, p. 94, 1913. To accompany forest plan, Plumas National Forest, district 5. Appendix (continued), Silviculture. (Unpublished. Furnished by courtesy of the U. S. Forest Service.)

² See also Zon, Raphael, Balsam fir, U. S. Dept. Agr., Bul. 55, 68 pp., 2 pls., 8 figs., 1914. (See p. 67.)

every case by the age of decline. The synthetic rotation is figured on the basis of the specific rotations, under due consideration of representation and relative value of each species from a commercial and silvical point of view. The same is true for cutting cycles. It should not prove impossible to express both representation and relative value for each species in symbols, which, together with the specific rotation, would permit the balancing of each species against the others, and thus to arrive at the synthetic rotation of the entire unit. In this way the inferior species will be given their proper place in forest regulation. This procedure is undoubtedly followed more or less consciously wherever regulation is planned by way of timber sales. It can not be reduced to a practical working system, however, until all factors upon which it is based are thoroughly known.

The pathological rotation limits the rotation of white fir, on the basis of our present knowledge, to 150 years—at least during the transition period. Perhaps the actual felling age for the species will be shortened long before that time arrives. The chances of providing for the next decades are distinctly better. On areas cut over to-day we may expect second operations in not too remote a future, taking the place of a second improvement felling. Provided our figures prove correct, the critical age and the age of decline will be a safe guide in tentatively fixing cutting cycles for white fir, which, together with the cutting cycles for the other species present, will permit the establishment of the synthetic cutting cycle for the unit.

Our present knowledge of the pathology of white fir leads us to the following practical conclusions for the period of transition:

Prejudice against white fir as an inferior species.

Conservative scaling (excluding advance rot) in favor of the purchaser on the one hand and of better utilization of sound white fir (where market conditions permit) on the other will in time overcome the prejudice.

Silvicultural treatment of white fir.

Reproduction: Frost and lightning zones are to be avoided.

Marking on timber sales:

On frost and lightning zones marking should be heavy.

Badly wounded trees, particularly those with open fire scars or frost cracks, should be marked heavily.

Badly suppressed trees should be marked heavily.

Trees with a combination of wounds and suppression can not be figured on to remain fairly sound beyond the critical age of about 130 years. The age of such trees, if left standing, added to the number of years to elapse before the presumable next cutting takes place, must not exceed 130 years.

Trees wounded, though thrifty, can not be counted on to remain sound beyond the age of decline of about 150 years. The age of such trees, if left standing, added to the number of years to elapse before the presumable next cutting takes place, must not exceed 150 years.

Rotation and cutting cycles.

The rotation for white fir, as far as we can judge now, can not exceed 150 years.

Cutting cycles for white fir must be limited by the age of decline.

OUTLOOK.

The weak point in the example (white fir) discussed in this paper lies in the fact that the numerical basis of trees examined is insufficient. Besides, what may be true for one set of conditions may prove wrong in another. Extensive additional studies on white fir in different regions of its range have been carried out during 1913.

What has been done for white fir must be done for the other species as well. Investigations on incense cedar have yielded suggestive results; others are to follow. But not before all important species, from the lowest to the most valuable, have been studied carefully with regard to their pathology can we expect to definitely figure the total-loss factor for any unit. To-day we are standing at the very beginning. Each species has its specific fungi, either one (as in the case of incense cedar), or practically one (as in the case of white fir), or several (as in the case of Douglas fir, sugar pine, and yellow pine). The relative importance of each of these fungi, their relation to influencing factors, their prevalence throughout the range of their hosts, and, finally, the establishment of the critical age and age of decline from a pathological point of view, are still to be worked out. To this we must add the study of all the other components of the total-loss factor.

The amount of work left to be done is enormous and will require many years. Concentration on the inferior species will yield results in a shorter time, enabling us to establish general rules to guide us in the transition period without causing too much damage to the interests of future generations.

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UNITED STATES DEPARTMENT OF AGRICULTURE



BULLETIN No. 380

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief



Washington, D. C.

PROFESSIONAL PAPER

January 15, 1917

ENDOTHIA PARASITICA AND RELATED SPECIES.

By C. L. SHEAR, *Pathologist*, and NEIL E. STEVENS,¹ *Pathologist, Fruit-Disease Investigations*, and RUBY J. TILLER, *Scientific Assistant, Office of Investigations in Forest Pathology*.

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TAXONOMY.

INTRODUCTION.

The discovery of a serious canker of the chestnut in the New York Zoological Park in 1904, by Merkel (49),² first attracted the attention of pathologists and foresters to what has proved to be one of the most serious epidemics of a plant disease ever known in this country.

The fungus which was found associated with these cankers (Pl. I and Pl. II, fig. 1) and soon demonstrated experimentally to be their cause was described by Murrill (57) in 1906 as a new species of *Diaporthe* (*D. parasitica*). Search for the fungus in other places in New York and vicinity soon showed that it was already established and apparently rapidly spreading. Investigations which have been continued and extended from year to year have shown

¹ Formerly Pathologist, Office of Investigations in Forest Pathology.

² Serial numbers in parentheses refer to "Literature cited," at the end of the bulletin.

NOTE.—This bulletin is of value to botanists, especially plant pathologists and mycologists, and to all persons who are interested in the study of chestnut blight.

conclusively that the disease is spreading very rapidly, especially west and south from New York and also north and east.

The exact identity and relationships of the fungus causing the disease and the origin of the epidemic soon became the subject of study by various mycologists and pathologists. Different explanations were offered for the sudden appearance and behavior of the disease, one view being that the fungus was probably a foreign parasite which had been introduced; another, that the organism was probably a native species which had recently attracted attention, chiefly by reason of the weakened condition of the chestnut trees due to abnormal climatic or other conditions.

In attacking the problem of the origin of the parasite and its possible control, it was evidently necessary to secure all the information possible in regard to its life history, identity, distribution, and relationships. The senior writer in an unpublished paper prepared in 1908 pointed out the close relationship and possible identity of *Diaporthe parasitica* with certain species of *Endothia*. Clinton (16) and Farlow (28) soon after also made the same suggestion. Two species of *Endothia* had already been described from this country by Schweinitz (74) under the old generic name, *Sphaeria*. These, however, had in recent years been regarded as a single species and referred to *Endothia gyrosa* (Schw.). Owing to a lack of knowledge of the types of these two species and for want of good specimens showing ascospores, it was difficult to determine what species of *Endothia* were indigenous in the eastern United States. Since it had been suggested that *Diaporthe parasitica* was either identical with one of Schweinitz's species or a mere variety of it, the present writers undertook a thorough study of the genus *Endothia* in its taxonomic, ecological, and pathological relations. It was first necessary to determine the identity of the two species already described by Schweinitz from America and also to learn their distribution and host relations. As one or both of Schweinitz's species were reported to occur in southern Europe on chestnut, it was important to obtain exact knowledge in regard to the identity and relationships of the European species. The senior writer spent several months in Europe collecting material of *Endothia* in the field and studying herbarium specimens of types and authentic collections of Schweinitz and other authors. Material was also acquired by collection and exchange with pathologists and mycologists in nearly every region of the world in which *Endothia* was known to occur. Comparative cultural studies were made of all the living material secured, as well as inoculation experiments on various hosts. The recent discovery of the typical chestnut-blight parasite, *Endothia parasitica*, by Meyer (27, 76, 78), in China and Japan and the failure to find in Europe or America any native form which would produce the disease appear to settle beyond question its foreign origin.

The present paper presents the results of several years' field and laboratory study of the species of *Endothia*. This includes the study of practically all the herbarium material of this genus preserved in the principal herbaria of Europe and America; also field and laboratory studies of over 600 new collections from various localities and hosts in America, Europe, and Asia. Over 4,000 cultures have been studied and about the same number of inoculations made. These studies include the systematic relations of the species of *Endothia* and their physiological behavior on various culture media and under various conditions of light, moisture, and temperature; also inoculation experiments with the various species on various hosts.

The writers wish to record here their grateful acknowledgment and thanks for opportunities to examine specimens and for assistance rendered by various mycologists and pathologists and directors and curators of botanical gardens and museums, especially the following: Prof. O. Comes, Naples; Prof. Romualdo Pirota, Prof. Giuseppi Cuboni, and Drs. E. Pantanelli and L. Petri, Rome; Prof. P. Baccarini, Florence; Prof. P. A. Saccardo, Padua; Dr. G. Briosi, Pavia; Dr. J. Briquet, Delessert Herbarium, Geneva; M. G. Beauverd, Boissier Herbarium, Geneva; Prof. L. Jost, Strasburg; Prof. W. Pfeffer, Leipzig; Dr. G. Lindau, Berlin; Dr. J. W. C. Goethart, Leiden; Prof. H. O. Juel, Upsala; Dr. P. Hariot, Paris; Sir David Prain, Kew; Dr. A. B. Rendle, British Museum; Prof. I. B. Balfour, Edinburgh; Prof. T. Petch, Peredeniya, Ceylon; Dr. C. Spegazzini, La Plata, Argentina; Dr. W. G. Farlow, Harvard University; Dr. W. A. Murrill, New York Botanical Garden; Mr. Stewardson Brown, Philadelphia Academy of Science; Dr. G. T. Moore, St. Louis Botanical Garden; Prof. E. Bethel, Denver, and Drs. G. P. Clinton, P. J. Anderson, and F. D. Heald. The writers have also received specimens and cultures from numerous other colleagues which have been of great assistance and are duly appreciated.

THE GENUS *ENDOTHIA*.

The genus *Endothia* was established by Elias Fries in 1849 (33, pp. 385-386), as follows:

(X. - *Endothia*. Fr.*)

* Colore rubro fulvove, habitu Tuberculariae, perithecii cellulosis difformibus pallidis, ascis diffluentibus, facile distinctum genus, nobis exoticum, sed jam in Europa australi obvium v. c. *Sph. gyrosa* Schw.—et subgenus, tuberculo uniloculari, sistit *S. Tubercularia* Dec. Omnium horum generum characteres proxime plenius exhibeamus, examinatis multis speciebus exoticis.

The description of the genus transcribed here was published as a footnote in the work cited and was evidently based on the specimens contained in Fries's herbarium at the time the book was written.

Fries (31, p. 73) had at that time, according to his own statement, authentic specimens of *Sphaeria gyrosa* sent him by Schweinitz and also the specimens collected by Guepin and Levieux in France, which he identified as this species. In Fries's herbarium at Upsala at present are found specimens of true *S. gyrosa* Schw. with Schweinitz's autograph label, but no specimens of *S. gyrosa* could be found attributed to Guepin or Levieux. There is a small packet marked "*Sph. gyrosa*," apparently in Fries's handwriting, but there seems to have been some confusion in the labeling or mounting of this specimen, as a small stroma of *Hypoxyylon annulatum* which does not look at all like *Endothia* is included. The other piece consists of an irregular pycnidial stroma which may be the southern European specimens referred to in the description quoted. Fries's identification of this European material as *E. gyrosa* was apparently based chiefly upon its superficial resemblance to the pycnidial stromata of Schweinitz's American specimens. The senior writer has seen and made a careful microscopic examination of a specimen collected by Guepin in France and preserved in De Notaris's herbarium at Rome. It is labeled "*Sphaeria gyrosa* Fries, Guepin, Angers." The specific name "*gyrosa*" has been crossed out by De Notaris and "*radicalis* Schw." written above it and the date "April, 1845," added. This appears to be a part of the same collection that Guepin sent to Fries, as the specimen agrees well with Fries's description and consists chiefly of pycnidial stromata which are rather larger than is usual for *Sphaeria radicalis* and show considerable superficial resemblance to the stromata of *Sphaeria gyrosa* Schw. A thorough examination of this specimen, however, reveals a few perithecia and ascospores, which leave no doubt that it is *S. radicalis* of Schweinitz, as indicated by De Notaris on the label. What the plant sent Fries by Levieux was is unknown, as no specimen so labeled could be found in Fries's herbarium. It appears from all the evidence at hand that Fries was mistaken in his identification of the material from Levieux and Guepin, as no specimens of the true *Sphaeria gyrosa* Schw. have yet been seen from Europe.

There seems to be no doubt, however, that Fries intended the true *Sphaeria gyrosa* Schw. to represent the type of his genus *Endothia*, as he had a part of Schweinitz's original collection at the time and never definitely placed any other species in the genus; hence, *Sphaeria gyrosa* Schw. should be adopted as the nomenclatorial type of the genus. It is clear from Fries's writings and specimens that he knew *Sphaeria radicalis* Schw., as he had American specimens from Schweinitz as well as European collections at the time he founded this genus. He did not, however, apparently regard it as congeneric with *S. gyrosa*. His specimens of *S. radicalis* show

the typical perithecia with necks, whereas no perithecia have been found in any of Schweinitz's specimens of *S. gyrosa* examined by the writers. Fries, in common with Schweinitz, regarded the pycnidial cavities of *S. gyrosa* as perithecia. When the pycnidia of *S. gyrosa* are mistaken for perithecia and compared with the real perithecia of *S. radicalis* the differences appear marked. It was therefore quite as natural for Fries to place the two species in different genera as it had been for Schweinitz to place them in different tribes of the genus *Sphaeria*. Fries's mistake in describing as perithecia the pycnidial cavities in the stroma of *S. gyrosa* explains his reference to the asci as "ascis diffluentibus." Believing that he had perithecia but finding no asci, he interpreted this as indicating that they had disappeared.

According to the plan of accepting only names originally applied to the ascospore stage, this name would be invalid, as proposed by Fries, and would be attributed to De Notaris, who placed the perithecial form of *Sphaeria radicalis* Schw. in the genus and described the ascospores. There is not the slightest question, however, in regard to the identity of the different stages of this fungus and their genetic connection, and the name *Endothia* has been almost invariably applied to these two species in both stages.

SYNONYMY.

There are only two true generic synonyms of *Endothia*: *Endothiella* Saccardo, 1906 (71, p. 278) and *Calopactis* H. and P. Sydow, 1913 (81, p. 82). *Endothiella* was based on *Endothiella gyrosa* Sacc., which, according to authentic specimens from Saccardo, is undoubtedly the pycnidial form of *Endothia fluens* as found in Italy. *Calopactis* was based on *C. singularis*, the pycnidial condition of *Endothia singularis* (H. and P. Syd.) S. and S. Ascospore cultures of this have not yet produced any pycnidia, but the proof of the genetic connection of the two stages appears rather conclusive from the occurrence of pycnidia and perithecia in the same stroma, as shown in Plate XII. Perithecial stromata and ascospores were also found in the specimen of the Sydow exsiccati in the Pathological and Mycological Collections of the Bureau of Plant Industry.

Von Höhnelt (43, p. 1479-1481) considers *Cryphonectria* Sacc. as a synonym of *Endothia*, taking *C. gyrosa* (B. and Br.) as the type of that genus because it is the first species listed by Saccardo in connection with his description of the genus. Saccardo, however, had previously established *Cryphonectria* as a subgenus, with *C. abscondita* as the type, which is not an *Endothia*. *Valsonectria* is also considered by Von Höhnelt a synonym of *Endothia*, but apparently he had not compared specimens of Spegazzini's fungus, which is found upon examination of the type species to be separate from *Endothia*. The

Tulasnes (83, p. 87-89) do not appear to have regarded *Endothia* as distinct from *Melogramma*, to which they referred *E. gyrosa*. The type of *Melogramma*, however, is *M. melogramma* (Bull.), which has a somewhat similar stroma, but the ascospores are 3-septate and dark colored and the perithecia not separable from the stroma, while the pycnosporos are long, slender, and curved.

STUDY OF EARLY COLLECTIONS AND TYPES.

There has always been more or less uncertainty in regard to the identity of the older species of this genus of fungi. In order to get more light on this subject, a thorough study of all the available material in the way of literature, type specimens, and manuscripts was made. The first species to be described in this country was *Sphaeria gyrosa* Schw. This was collected by Schweinitz at Salem, N. C., and published in 1822 (72, p. 3).¹ Two hosts were given in the original description, *Fagus* and *Juglans*.

As Schweinitz's description was prepared before the advent of careful microscopical studies and spore measurements, it is impossible to identify the organism satisfactorily from the original description. It was, therefore, important, if possible, to locate the type specimens upon which the description was based. Schweinitz's herbarium was left at his death, in 1834, to the Philadelphia Academy of Science. His specimens of fungi at the time they were transferred to the academy were contained in small, folded paper packets, as shown in Plates V and VI. These packets were then inclosed in other heavy paper wrappers, folded to small quarto size, and three or four of these large packets, each bearing a manuscript list of the species contained, were then inclosed in quarto pasteboard covers, tied with tape. The individual species packets were labeled in Schweinitz's handwriting, with the name of the species and the locality of the collection, as shown in Plate V, figure 2.

These species packets frequently bore the names of several localities, but usually two, Salem [N. C.] and Bethlehem [Pa.], as most of his collecting was done at these places. This fact, in addition to the evidence afforded by the specimens in the packets, clearly indicates Schweinitz's method of handling his specimens.

Frequently some of the specimens in a packet show the remains of a gummed strip. This will be noticed in Plate III, which indicates

¹ 24. *Sphaeria gyrosa* Sz.

S. subperipherica minor gregaria subconfluens aurantio miniata, sphaerulis gyrosis farctis demum prominulis pulverulentis, stromate lutescenta.

In cortice nondum corrupto etiam vivo Fagorum et Juglandum. Junior planiuscula, ubi adolevit sistit corpus subrotundum, tuberculis minimis et magoribus asperum et gyrosum. Sphaerulae farctae, teretes, supra gyrosae, paucae, radiatim divergentes a superficie ad centrum fere stromatis continuantur, primum sublantes, demum prominulae, cortice pulverulento; ipsum tamen centrum farinacea carne componitur. Gelatina asciphora albet. Ostiola indistincta.—Transitum facit ad *Sphaerias* septimae divisionis.

that at one time the specimen was apparently attached to a sheet by a gummed paper strip. This seems to have been the way in which Schweinitz originally mounted his specimens, but later, apparently, he changed to the plan of putting them in paper packets and removed those which had been attached to sheets. It is clear from an examination of the specimens still found in some of the original packets that two or more different hosts were sometimes included. In some cases as many as four or five different collections appear to have been placed in the same packet and each new locality added on the outside. This method of keeping specimens makes it rather difficult in some cases to determine which belongs to the first collection. In the case of *Sphaeria gyrosa* but two localities are indicated on the packet, Salem and New England. (See Pl. VI, fig. 2.)

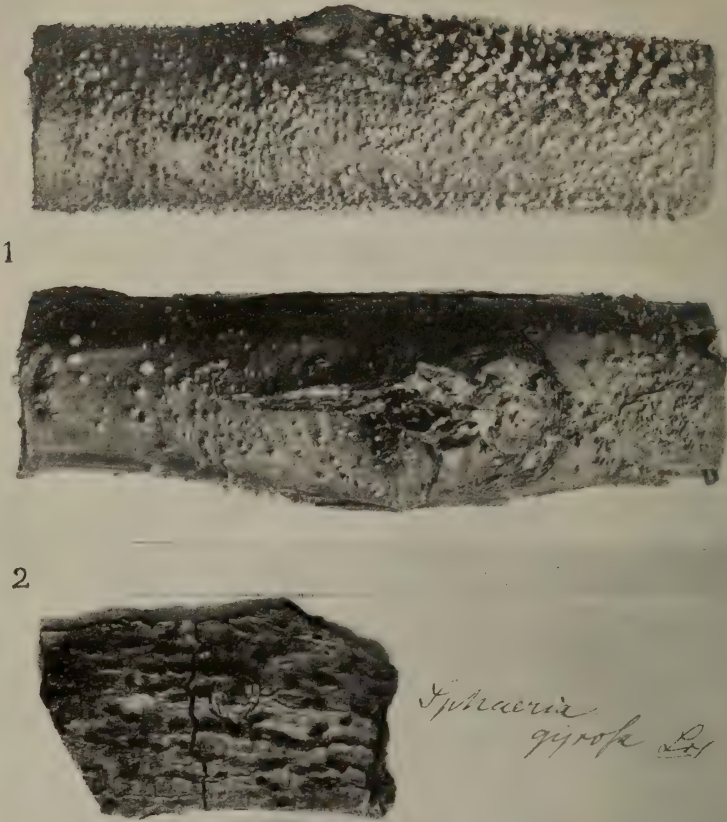
The difficulties in determining the true type specimen of any species would have been sufficiently great if the collection had been preserved as it was left by Schweinitz. The matter is, however, further complicated by the later handling and rearrangement of the collection. Some time after Schweinitz's death (the exact date the writers have been unable to determine) his collection of fungi was more or less completely rearranged and mounted. The greater part of this work was evidently done by Dr. Ezra Michener. Dr. Michener was a lifelong resident of Chester County, Pa. He early became interested in botany, and in 1840 was elected a correspondent of the Philadelphia Academy of Natural Science. He paid special attention to the collection and study of fungi and corresponded and exchanged with various mycologists, especially Curtis and Ravenel. He left a large collection of fungi, which the writers have recently had the privilege of examining. Among his specimens are found many labeled "Ex. Herb. Schw.", which are undoubtedly part of Schweinitz's original collections at the Philadelphia Academy. These specimens, as well as all of Michener's fungi, are mounted in exactly the same manner as the mounted portion of Schweinitz's collection at the Philadelphia Academy. The mounting paper, the specimen slips, the arrangement, manner of attachment, and the handwriting on the labels are identical, as will be readily perceived by comparing the illustrations from photographs of sheets from both herbaria. It is, therefore, clear that the mounted collection of Schweinitz's herbarium was prepared by Dr. Michener. He evidently took from Schweinitz's original paper packets what appeared to him to be the best or most typical specimen of the species in the packet and attached it with glue to a square slip of paper, as shown in Plate III. Where there was but little material in the original packet it was all mounted in this manner. In case there were several pieces in the original packet he used his own discretion in making the selection of the part to be mounted and the part to be left.

When there were included in the original packet specimens from different hosts or different localities, in some cases representing different species, it would have been difficult, if not impossible, to determine which was the original material from which Schweinitz's description was made. At the same time, Dr. Michener, in case the specimen was not too scanty, evidently took a small portion of it for his own herbarium. Michener's catalogue of his herbarium lists *Sphaeria gyrosa* Schw. Consulting his collection it is found that No. 1431, the number of Schweinitz's specimen, is missing. Pin holes in the mounting sheet, however, show that the specimen which was once there has been removed. As perhaps throwing some light on the possible location of this specimen, it may be said that a specimen apparently typical *S. gyrosa*, pycnidial form on beech, labeled by Dr. William Trelease as *Sphaeria gyrosa* from Pennsylvania, was seen in the Boissier Herbarium, Geneva. Dr. Trelease tells the writers that this specimen probably came from Dr. Michener, and as there is no evidence that Dr. Michener or any one else has collected *E. gyrosa* in Pennsylvania there is considerable probability that this specimen represents a portion of Schweinitz's original collection.

In most cases all of the material in Schweinitz's original species packets was removed and either mounted or distributed. This was the case with *Sphaeria gyrosa*. The original packet of Schweinitz, which was fortunately preserved with all the others, is empty and apparently a part at least of the specimen which it contained is found in the mounted collection as prepared by Michener. This consists of a single piece of bark shown in Plate VI, figure 1. From the evidence the writers have been able to gather from Schweinitz's manuscripts and correspondence, as well as from studies of his writings and specimens in other herbaria, it appears that this specimen is the one indicated on the original packet and also by Schweinitz (74, p. 206) as having been collected in New England and sent to him by Torrey. This, as shown by his correspondence, was after he had left North Carolina. The bark upon which the fungus grew is clearly not *Fagus*, *Juglans*, or *Quercus*, the hosts originally given for *S. gyrosa*, but apparently *Acer*. It is therefore not a part of the original specimens from Salem, N. C., upon which his description was based, and in reality is not *Sphaeria gyrosa*, but a species of *Nectria*, which Schweinitz incorrectly identified as *S. gyrosa*. Portions of this same specimen are found in Berkeley's herbarium at Kew and in the Curtis herbarium at Harvard. They are clearly the *Nectria* referred to above from Torrey. In this connection, it may be noted that E. Hitchcock in 1829 (42, p. 63) reports *Sphaeria gyrosa* Schw. from Amherst, Mass., and states in the preface to his list that Dr. Torrey assisted in the determination of the cryptogams.



"CANKERS" CAUSED BY *ENDOTHIA PARASITICA* ON *CASTANEA DENTATA*. $\times \frac{1}{2}$.



HERB. MUS. PARIS.

Melogramma *gyrosum*

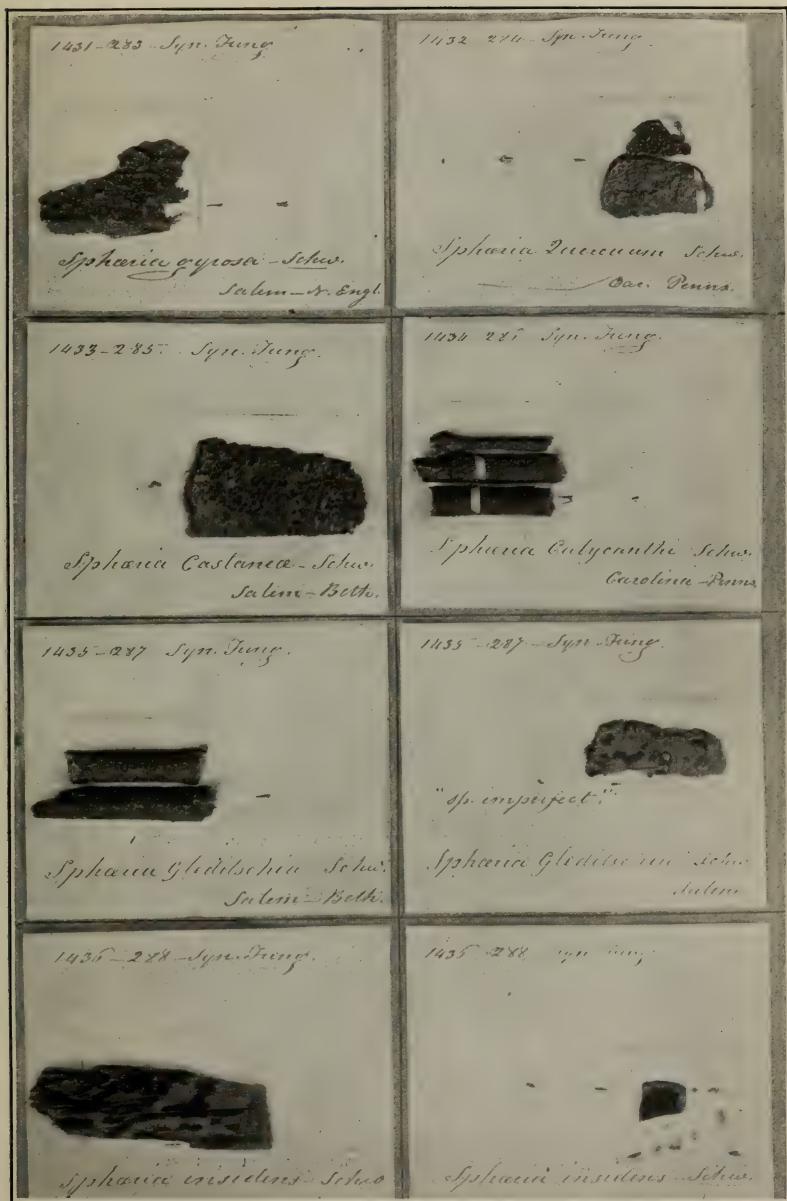
Caulina *rupestris*
(*leucosperma* Schw.)

D. Schweinitz
ad.

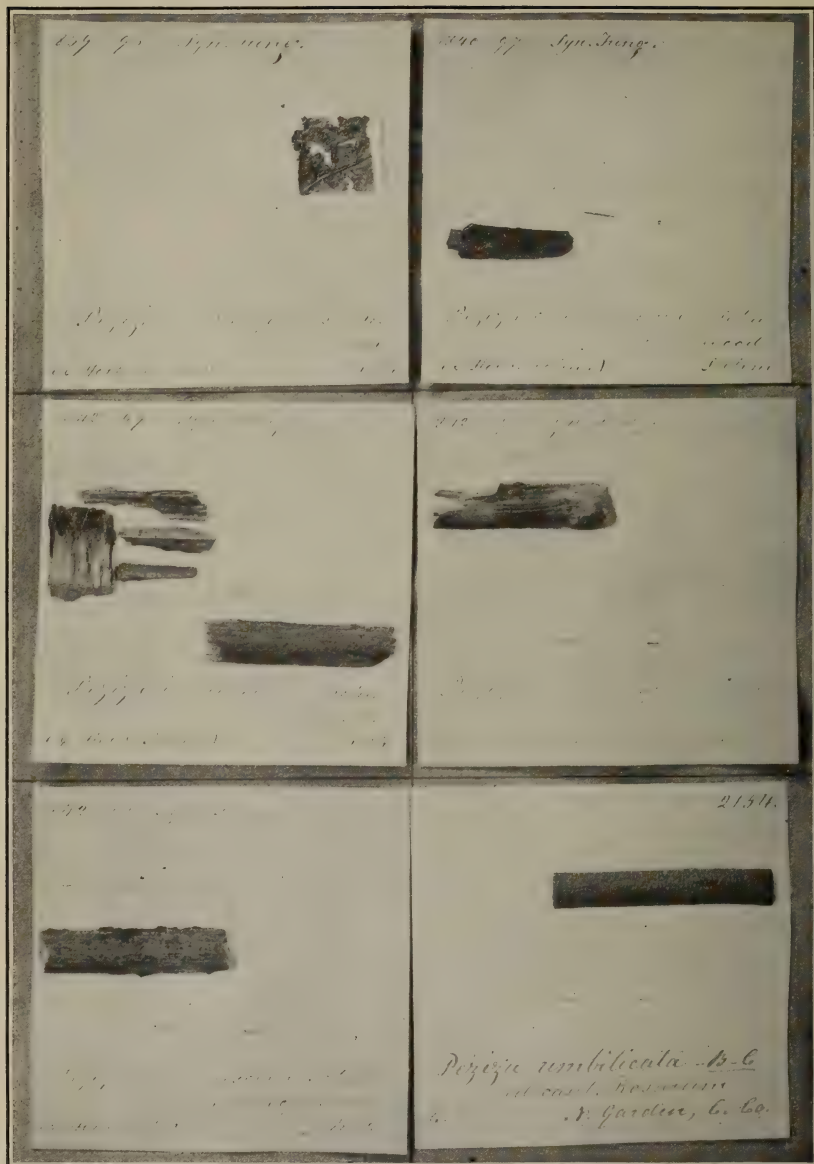
(Ex. herb. Ad. Brongniart. Anno 1843).

FIG. 1.—PERITHECIA AND PYCNIDIAL STROMATA OF *ENDOTHIA PARASITICA* WITH CANKERS ON *CASTANEA DENTATA*. FIG. 2.—COTYPE OF *SPHAERIA GYROSA* SCHW. ON *FAGUS*.

Specimen now in the Paris Museum sent to Brongniart by Schweinitz, showing Tulane's label "*Melogramma gyrosum*" and Schweinitz's autograph label.



A SHEET FROM THE MOUNTED PORTION OF SCHWEINITZ'S HERBARIUM AT THE PHILADELPHIA ACADEMY OF SCIENCES, SHOWING SPECIMENS AS PREPARED AND LABELED BY MICHENER.



A SHEET FROM MICHENER'S HERBARIUM, SHOWING A PART OF SCHWEINITZ'S TYPE OF PEZIZA CINNABARINA (UPPER RIGHT HAND CORNER); ALSO SHOWING CLEARLY THAT THE MOUNTING AND LABELING OF THIS AND SCHWEINITZ'S COLLECTION WERE DONE BY THE SAME PERSON.

This seems to explain the origin of the specimen which Schweinitz received from Dr. Torrey. The writers have searched in vain for *Endothia gyrosa* in Amherst and vicinity and they know of no collections of the fungus from Massachusetts. No specimens upon which Hitchcock's list was based have been located.

Since it can be clearly shown that little or none of the original type collection of this species is in the Philadelphia Academy collection it must be looked for elsewhere. It is found by reference to Schweinitz's correspondence and manuscripts, which have been carefully examined by the writers through the courtesy of the Philadelphia Academy and the descendants of Schweinitz, and also by studies in foreign herbaria that he divided his specimens with many of his European and American correspondents. As he does not appear to have kept any duplicates separate from his regular collection it seems probable that the specimens he distributed were taken from the original packets. Thus in some cases, apparently all of a type specimen was removed from the original packet. In fact, in one instance (73, p. 5) he states that he sent his only specimen of a species of *Hypoxyylon* to Dr. Schwaegrichen, of Leipzig.

It seems rather certain from statements made by Schwaegrichen in his introduction to Schweinitz's paper on the fungi of North Carolina (72) that specimens of a large number, if not all, of the species represented in that work were sent to him. The types or parts of the types should therefore be found in Schwaegrichen's herbarium. In spite of all their efforts, however, through correspondence and personal search in Europe, the writers have been unable to locate Schwaegrichen's collection of fungi. They found, however, in the herbarium of the University of Leipzig a small bit of a specimen labeled "*Sphaeria gyrosa* Schwein. *Juglans Fagus Carolina* D. Schwaegrich. dd 5-21 K. Z." This specimen is evidently a part of the original collection of Schweinitz which was sent to Schwaegrichen and given by him to Dr. Kunze. The host is apparently neither *Juglans* nor *Fagus*, but seems to be *Quercus*. It may be noted in this connection that in spite of diligent search by the writers and various other collectors no specimen of *Endothia* has yet been found on *Juglans* in this country. Neither have the writers been able to find any specimen in the various herbaria examined. They have concluded, as a result of their studies, that the mention of *Juglans* by Schweinitz was an error in the identification of the host, which it is believed was really *Quercus*, the host upon which *E. gyrosa* is most frequently found in the South, and especially in the vicinity of Salem. According to the American Code,¹ however, the specimen which should be taken as the type in this case is the one on

¹ American Code of Botanical Nomenclature. Canon 14, b. Bulletin, Torrey Botanical Club, vol. 34, p. 172. 1907.

Fagus, as this is the first-mentioned host in the original description. No specimen of this species on *Fagus* from Schweinitz was found in Kunze's collection. However, authentic specimens from Schweinitz on *Fagus* have been found in Fries's herbarium at Upsala, in Hooker's herbarium at Kew, and in Brongniart's herbarium in the Paris Museum. The last, which is the largest and best specimen, is shown in Plate II, figure 2. Microscopic studies of the specimens at Paris and Kew show only pycnidia with pycnospores. The writers were unable to examine microscopically the specimen in Fries's herbarium, but it agreed in all macroscopic respects and also, so far as could be determined with a hand lens, with the Paris and Kew specimens. These specimens agree with all the material collected on *Fagus* from various localities in the South. Studies of numerous collections of *E. gyrosa* have shown that the pycnidial form can be distinguished with certainty from any of the other species of *Endothia* at present known. The connection between this pycnidial form and the perithecial form as described has been demonstrated by pure cultures from ascospores and also by the association of typical pycnidia and pycnospores with perithecia and ascospores in the same stroma. There appears to be no reasonable doubt, therefore, that the specimens collected by Schweinitz on *Fagus* were the pycnidial form of *Endothia gyrosa*, and the specimen in the Paris Museum which was sent by Schweinitz to Brongniart about 1825 may properly be considered a cotype of Schweinitz's species. The specimen from Schweinitz in Kunze's herbarium at Leipzig also proves on microscopic examination to be the pycnidial form of the same fungus. It is probable from the evidence at hand that Schweinitz did not collect any specimen showing ascospores of this fungus. However, the specimen in Kunze's herbarium shows some perithecia evidently immature and without spores. A part of the specimen from Schweinitz in Fries's herbarium shows stromata on a piece of bark, evidently not *Fagus*, but probably *Quercus*. This also appears to be pycnidia only.

The specimen referred to by Clinton (18), which was found in the original packet of Schweinitz at Philadelphia with *Sphaeria enteromela*, is also undoubtedly the pycnidial form of *E. gyrosa*, which closely resembles some early stages in the development of species of *Hypoxylon*, especially *H. enteromela*. These species may be easily confused with each other, and this would seem to be a probable explanation of the accidental presence of this specimen in this packet. Another point of interest in this connection is the fact that in spite of diligent search on the part of the writers and many other collectors and an examination of numerous specimens of *Endothia* on *Fagus* in all stages of development and from different localities only *Endothia gyrosa* has been found on this host. Of

course, it can not be positively stated that *E. fluens* does not occur on *Fagus* in this country, but if it does it must be rare. In this connection, it is also perhaps worthy of note that, notwithstanding the mention of *Fagus* as a host in Europe, the writers have never seen any European specimens of *Endothia* on this host. The specimens so named by Roumeguere and distributed as No. 989 Fun. Gal. on beech are, according to several specimens examined, evidently a young condition of some *Hypoxylon*, probably *H. coccineum*, which in this state bears a superficial resemblance in form and color to the stromata of *Endothia*, but can be easily distinguished by the dark-brown or blackish color of the interior of the stroma. The identity of Schweinitz's *Sphaeria gyrosa* with the long ascospore form of *Endothia* shown on Plate VII is based on careful microscopic study of the stromata and measurement of the pycnospores from four specimens of the original collections of Schweinitz in North Carolina, three on *Fagus* and one labeled *Juglans*. The three on *Fagus* show the typical pycnidial stromata and pycnospores of the species, either of which is sufficient for positive identification when thoroughly known. The specimen referred to by Schweinitz as on *Juglans* also shows typical pycnospores of *E. gyrosa*. The evidence, as stated above, leaves no reasonable doubt as to the identity of the fungus which Schweinitz described as *Sphaeria gyrosa*.

According to a specimen which is probably a portion of Schweinitz's type found in Michener's herbarium, *Peziza cinnabarina* Schw. is the pycnidial form of *E. gyrosa* (Schw.) (See Pl. IV.) It is the form with small pycnidia on bare wood of *Liquidambar*. This was first reported by Schweinitz as "*Peziza flammea* A. and S." and later changed as above. Later Saccardo (69, vol. 8, p. 399), thinking that this was a *Discomycete*, transferred it to the genus *Lachnella*.

The other American species of *Endothia* which was described by Schweinitz as *Sphaeria radicalis* and first published by Fries in 1828 (31, p. 73) has also until recently been more or less misunderstood. The only specimens of this species found at present in Schweinitz's mounted collection at the Philadelphia Academy of Science is a small piece of bark of an oak root bearing a few pycnidial stromata. No host was given in Fries, but Schweinitz in 1832 (74 p. 197) gives *Fagus* as the host. That this was an error and that the host was really *Quercus* and not *Fagus* is clearly indicated by all of Schweinitz's specimens examined, not only those in the Philadelphia Academy but those found in several herbaria in Europe and one in Curtis's herbarium at Harvard, and also in Schweinitz's autograph label on the original packet in his herbarium. A photograph of this packet is shown in Plate VI.

The description of this species was first published by Fries in 1828 (31, p. 73). Schweinitz's specimen at the Philadelphia Academy

shows only pycnidia. (See Pl. V, fig. 2.) His description, however, as well as his unpublished illustrations preserved in the library of the Academy, show clearly that perithecia were present in the material from which the description was made. This is also conclusively shown by authentic specimens from Schweinitz in at least two European collections, those of Fries at Upsala and Hooker at Kew. A microscopic examination of these specimens shows good perithecia and mature ascospores having the characters and measurements given elsewhere in this paper for *Endothia fluens* (Sow.). (See Pl. XVII, fig. 9.) As there is no indication in Schweinitz's writings or in his manuscript notes and records that he made more than one collection of this species, there is no reason to doubt that the material at Upsala and Kew is a part of that upon which he based his description of *Sphaeria radicalis* Schw. The true type specimen of the species is that in Fries's herbarium upon which he based his description, which was added to the diagnosis sent by Schweinitz.

One year after the description of this species from America it was reported from Italy by Rudolph, in 1829 (66, p. 393), and in 1830 Fries (32, p. 541) himself reports the fungus from France. This species had, however, been collected and described before in its pycnidial condition in 1814 by Sowerby (79, pl. 438) under the name of *Sphaeria fluens*. This was reported in 1836 by Berkeley (8, p. 254) as *Sphaeria gyrosa* Schw. A microscopic study of the original material of this species, which was collected by Charles Lyell on chestnut in the New Forest in southern England and is now preserved in the Kew Herbarium, leaves no doubt that it is the pycnidial form of *Endothia radicalis* (Schw.). Plate XVII, figure 3, shows pycnospores from Sowerby's specimen at Kew. This specimen agrees with Sowerby's illustration and is apparently the one from which this figure was made. The pycnospore masses are somewhat larger than usual; otherwise it is typical of *E. radicalis* Schw.

At first it did not seem possible to distinguish the species of *Endothia* in their pycnidial condition, but thorough microscopic studies of large quantities of material in the field and laboratory in both America and Europe have shown that the two sections of the genus and some of the species can usually be separated with certainty in this stage of their development, as indicated by the tables of measurements and in the photographs of pycnospores, and especially by the stromata of the different species.

The first description of the ascospores of *E. radicalis* was given in 1858 by Currey (21, p. 272), who examined the specimens from Schweinitz in Hooker's herbarium at Kew. Currey figured what he believed to be four ascospores. Two are apparently typical *E.*

fluens; the other two are more than 1-septate and belong to some other organism. Cesati and De Notaris, in 1863 (11), first definitely referred *Sphaeria radicalis* Schw. to Endothia. Up to this time *Sphaeria gyrosa* and *Sphaeria radicalis* were generally regarded by mycologists as separate species and were placed by Schweinitz and Fries in different groups of the genus *Sphaeria*, though they both mention a similarity in external appearances.

In 1863 the Tulasnes, in their epoch-making work on the fungi (83, pp. 87-89), made a careful microscopic study of the specimens from Schweinitz preserved in the Paris Museum and also specimens received from De Notaris, Berkeley, and other collectors. At that time no ascospores of *Sphaeria gyrosa* had apparently been described by mycologists. The material of *S. gyrosa* from Schweinitz which the Tulasnes found in the Paris Museum included the specimen on *Fagus* which had been sent by Schweinitz to Brongniart. There seems to be no evidence that the Tulasnes examined other specimens from Schweinitz or that they examined any specimens showing ascospores of the true *Sphaeria gyrosa*. This is indicated by their description and measurements of the ascospores. From their studies of Schweinitz's specimens and from other Carolina specimens sent them by Berkeley they concluded that *Sphaeria gyrosa* and *Sphaeria radicalis* are the same species and called it *Melogramma gyrosum*.

Fries (33, pp. 385-386) had earlier (1849) reported *Sphaeria gyrosa* as occurring in southern Europe. This report was apparently based upon specimens of pycnidial stromata of *E. fluens*, somewhat larger and more irregular in shape than usual, collected in western France by Guepin and Levieux and already referred to.

The statement of the Tulasnes (83, pp. 84-89) in regard to the identity of these species was accepted by practically all mycologists down to 1912, when the discussion in regard to the origin and relationships of *Endothia parasitica* commenced. Ellis and Everhart in 1892 (26, p. 552) apparently figured the true *E. gyrosa* Schw. but cited exsiccati of both *E. gyrosa* and *E. fluens* and gave the ascospore characters and measurements of *E. fluens*, apparently copied from Winter (85, p. 803), as the spores figured do not agree with the description.

THE SPECIES OF ENDOTHIA.

ENDOTHIA Fries, 1849, Sum. Veg. Scand., p. 385.¹

SYNONYMS:

Endothiella Sacc., 1906, in Ann. Mycol., v. 4, no. 3, p. 273. Type species, *E. gyrosa* Sacc., 1 c.

Calopactis H. and P. Syd., 1912, in Ann. Mycol., v. 10, no. 1, p. 82. Type species, *C. singularis*, 1 c.

¹ All references to literature in synonymy are given in full in "Literature cited," p. 77.

Stromata subcorticular in origin, variable in size and shape, pustular to subspherical, subcoriaceous to friable, sometimes confluent, surface light auburn¹ or chestnut to mahogany red, capucine yellow or cadmium orange to scarlet within; pycnidial and perithecial stromata the same or similar; pycnidia few to numerous, consisting of simple cavities or complex and irregular chambers; pycnosporos minute, simple, bacilliform to oblong, yellowish to reddish in mass; perithecia deeply immersed, in one or more irregular layers, usually black when mature, with long necks, black within, colored like the stroma without; asci clavate to oblong fusoid, 8-spored, usually without paraphyses; ascospores oblong fusoid or subellipsoid to cylindric or allantoid cylindric, uniseptate or non-septate, hyaline to pale yellowish.

Section 1.—Ascospores short cylindric to allantoid, continuous or pseudoseptate.

ENDOTHIA GYROSA (Schw.) Fries, 1849, *Sum. Veg. Scand.*, p. 385. p. p.

SYNONYMS:

- Pycnidia: *Sphaeria gyrosa* Schw., 1822, *Syn. Fung. Car. Sup.*, p. 29, no. 24.
Peziza flammea Schw. (not. Alb. and Schw.), 1822, *Syn. Fung. Car. Sup.*, p. 93, no. 41, p. p. ad Liquidambar.
Sphaeria gyrosa Fries, 1822, *Syst. Mycol.*, v. 2, p. 419.
Peziza gyrosa Spreng., 1827, *Syst. Veg.*, v. 4, pars. 1, p. 515.
Peziza cinnabarina Schw., 1832, *Syn. Fung. Am. Bor.*, p. 173.
Melogramma gyrosum, L. R. and C. Tul., 1863, *Selecta Fung. Carpol.*, t. 2, p. 87. p. p. min.
Melogramma gyrosum M. A. Curtis, 1867, *Cat. Indig. Nat. Plants*, p. 143.
Endothia gyrosum (Tul.) Fekl., 1869, *Symb. Mycol.*, p. 226.
Melogramma gyrosum Tul., Rav., 1879, *Fung. Amer. Exs.*, no. 352.
Lachnella cinnabarina Sacc., 1889, *Syll. Fung.*, v. 8, p. 399.
Perithecia: *Sphaeria gyrosa* Schw., Rav., 1852, *Fung. Car. Exs.*, no. 49.
Melogramma gyrosum Tul., Cooke, 1878, in *Ann. N. Y. Acad. Sci.*, v. 1, no. 5/6, p. 185.
Endothia gyrosa Fekl., Sacc., 1882, *Syll. Fung.*, v. 1, p. 601. p. p. min.
Endothia gyrosa Schw., Ell. and Ev., 1887, *No. Amer. Fung. Exs.*, no. 1956.
Endothia gyrosa (Schw.) Ell. and Ev., 1892, *No. Amer. Pyren.*, p. 552, p. p.
Endothia radicalis (Schw.) Farl., Clint., 1912, in *Science*, n. s., v. 36, no. 939, p. 908.
Endothia radicalis (Schw.) Shear, 1912, in *Phytopathology*, v. 2, no. 5, p. 211.
Endothia radicalis (Schw.) Fries, P. J. and H. W. And., 1912, in *Phytopathology*, v. 2, no. 5, p. 210.

TYPE SPECIMEN.—The type in Herb. Schw. is wanting. A cotype is in Herb. Museum of Paris.

PYCNIDIA.—Stromata corticular or subcorticular, pulvinate to tubercular, rugulose, scattered or gregarious, occasionally confluent, 1.5 to 3 mm. in diameter by 1.5 to 2 mm. high, orange chrome when young to chestnut when mature,

¹ In the following descriptions of cultures and elsewhere throughout this paper, the names of colors are taken from Ridgway's recent work on color nomenclature (64).

becoming almost black when old and weathered, cadmium orange within; pycnidia consisting of numerous irregular labyrinthiform chambers in the stroma, separated by walls of varying thickness and opening by irregular pores in the surface of the stroma; sporophores cylindric or slightly tapering toward the apex, 6 to 9 μ long; pycnospores oblong, straight or sometimes slightly curved, appearing hyaline when separate, warm buff to ochraceous buff or darker, according to mass and moisture content, 3 to 4 by 1.5 to 2 μ .

PERITHECIA.—Stromata the same or similar to those producing pycnidia; perithecia dark, membranous, few to many, mostly 25 to 50, usually arising in the lower portion of the stroma, 150 to 300 μ in diameter, very irregularly arranged in one to several layers, prolonged into slender necks which penetrate the stroma above and sometimes protrude somewhat, terminating in a short conical ostiole; asci oblong fusoid or subclavate, very short stipitate, 25 to 30 by 6 to 7 μ ; ascospores irregularly biseriate, cylindric to allantoid, 7 to 11 by 2 to 3 μ , mostly 7.5 to 10 by 2 to 2.5 μ , hyaline when separate, slightly yellowish in mass, with a very thin gelatinous envelope when mature.

CULTURAL CHARACTERS.—Cultures one month old on white corn meal show an abundant thick growth of mycelium producing irregular tubercular masses resembling pycnidial stromata, but without spores. The surface color is capucine buff. The medium usually changes to perilla purple. It is distinguished from *E. singularis*, its nearest relative, by its more rapid growth and the formation of the large tubercular masses.

HOSTS.—Exposed roots and branches: *Quercus alba*, *Q. coccinea*, *Q. falcata*, *Q. georgiana*, *Q. ilicifolia*, *Q. imbricaria*, *Q. marylandica*, *Q. nigra*, *Q. phellos*, *Q. prinus*, *Q. rubra*, *Q. velutina*, *Q. virginiana*, *Liquidambar styraciflua*, *Fagus americana* and *F. sylvatica* cult. vars., *Castanea dentata* and cult. vars., and *Vitis* sp. (25).

A specimen of this species collected by Ravenel has the host given as maple (*Acer*), but microscopic examination shows it to be *Liquidambar*.

TYPE LOCALITY.—Salem, N. C.

GEOGRAPHICAL DISTRIBUTION.—Southwestern Connecticut to central Michigan, southward to Florida and Texas; also Kansas and California.

ILLUSTRATIONS.—Ell. and Ev., 1892, No. Amer. Pyren., pl. 36, fig. 68; Clint. 1913, in Conn. Agr. Exp. Sta. Rpt., 1911, 1912, pl. 28, fig. a, d, and g.

EXSICCATI.—Pycnidia: Baker, Pl. Pac. slope, 722, on *Quercus agrifolia*; Rav. Fung. Amer., 352, on *Quercus*. Perithecia: Ell. and Ev. No. Amer. Fung., 1956, on *Quercus*; Rav. Fung. Car., 49, on *Quercus* and *Liquidambar*.

ENDOTHIA SINGULARIS (H. and P. Syd.) S. and S. nov. comb.

SYNONYMS:

Pycnidia: *Calopactis singularis* H. and P. Syd., 1912, in Ann. Mycol., vol. 10, no. 1, p. 82.

Endothia gyrosa Ell. and Ev., in Herb. N. Y. Bot. Gard.

Endothia gyrosa (Schw.) Fekl. Höhnelt, 1913, in Sitzber. K. Akad. Wiss. [Vienna], Math. Naturw. Kl., Abt. 1, Bd. 122, Heft 2, p. 298.

TYPE SPECIMEN.—H. and P. Syd., Fung. Exot., no. 88, on *Q. gambellii*.

PYCNIDIA.—Stromata corticular, erumpent, depressed globose, sometimes irregular, scattered, or gregarious, 3 to 5 mm. wide by 2 to 4 mm. high, outer wall thick, coriaceous, becoming brittle, mahogany red without, scarlet within; pycnidia consisting of innumerable nearly spherical cavities throughout the stroma, 25 to 35 μ in diameter, the walls disintegrating into a powdery mass and the whole set free by the irregular rupture of the stroma wall, usually leaving a cup-like basal portion attached to the bark; sporophores, according to the Sydows,

short, hyaline, subulate, 6 to 8 by 1 μ ; pycnospores ovoid oblong, hyaline, the contents of each pycnidial cavity adhering in a globular mass, when set free, 3 to 4 by 1 to 1.5 μ .

PERITHECIA.—Stromata the same or similar to those producing pycnidia; perithecia membranous, few to many, usually 100 or more, 200 to 350 μ in diameter, irregularly arranged in several series, prolonged into slender necks which sometimes protrude from the stroma; ostioles depressed conical; asci, oblong cylindric or subclavate to fusoid, substipitate, 25 to 35 by 4.5 to 5.5 μ ; ascospores irregularly biseriate, cylindric to allantoid, with a thin gelatinous envelope, hyaline when separate, slightly yellowish in mass, 7 to 11 by 1.5 to 3 μ ; mostly 7.5 to 10 by 2 to 2.5 μ .

CULTURAL CHARACTERS.—Cultures one month old on white corn meal have a cadmium and orange to capucine buff mycelium. It is distinguished from *E. gyrosa* by its slower growth and brighter color and the want of tubercular, stromalike masses. No spores of this species have been produced in any of the writers' cultures.

HOSTS.—*Quercus gambellii*, *Q. leptophylla*, *Q. nitescens*, *Q. utahensis*. Bethel also reports it on *Q. pungens*.

TYPE LOCALITY.—Palmer Lake, Colo.

GEOGRAPHICAL DISTRIBUTION.—Colorado and New Mexico.

ILLUSTRATIONS.—Pycnidia: H. and P. Syd., 1912, in *Ann. Mycol.*, vol. 10, no. 1, p. 82, figs. 1-5.

EXSICCATI.—Pycnidia and perithecia: H. and P. Syd., *Fung. Exot.*, 88, on *Quercus*. Pycnidia: Bart. Fung. Col., 4002, on *Quercus utahensis*.

In shape and size of pycnospores and ascospores this species closely resembles *E. gyrosa*, but is easily separated by the much greater size of its stromata, its brighter color and very numerous, small, regular pycnidial cavities and more numerous perithecia, as well as its geographical distribution.

The specimens of the Sydow exsiccati, No. 88, in the Pathological and Mycological Collections of the Bureau of Plant Industry show both pycnidia and perithecia.

Section 2.—Ascospores oblong fusiform to oblong ellipsoid, uni-septate when mature.

ENDOTHIA FLUENS (Sow.) S. and S. nov. comb.

SYNONYMS:

Pycnidia: *Sphaeria fluens* Sow., 1814, *Col. Fig. Engl. Fungi*, Sup. pl. 438, figs. 1, 2.

Sphaeria gyrosa Berk., 1836, *Brit. Fungi*, p. 254. Not Schw.

Endothia gyrosa Fries, 1849, *Sum. Veg. Scand.*, p. 385. p. p. *Europ.*

Sphaeria radicalis Fckl., 1861, *Enum. Fung. Nass.*, p. 76, no. 640.

Endothia gyrosum Fckl., 1869, *Symb. Mycol.*, p. 226. p. p. spec. cit.

Endothia gyrosa (Schw.) Fckl., forma *castaneae vescae* Sacc., 1876, *Mycol. Ven. Exs.*, no. 929.

Endothiella gyrosa Sacc., 1906, in *Ann. Mycol.*, v. 4, no. 3, p. 273.

Perithecia: *Sphaeria radicalis* Schw., Fries, 1828, *Elenchus Fung.*, v. 2, p. 73.

Sphaeria radicalis Schw., Rudolphi, 1829, in *Linnaea*, Bd. 4, Heft 3, p. 393.

Sphaeria radicalis Schw., Fries, 1830, in *Linnaea*, Bd. 5, Heft 4, p. 541.

7. *Tril* *Verfulides*

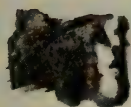
10. *S. radicalis* *Los*

Nature rare, & not without affinity to *S. gregaria* occurs on the roots of dead oaks, where they appear above ground, budding from the base. Salem & Betul.

S. gregaria variegans ex epidermide radicali; fibrinunda nigra, aurantis. miniata, substantia friabili crassiuscula, intus pallide alvantiaca; pulvinulis minutis sub confluentibus. Conspicuis. ~~maximula~~ ^{maximula} ~~regum~~ ^{regum} ~~ser~~ ^{ser} ~~me~~ ^{me} ~~imbricis~~ ^{imbricis} ~~atris~~ ^{atris} in collem longiusculum protractis, saepe in superficie elevatum, apiculis istius ~~regis~~ ^{regis} cylindricis aut irregularibus, ~~maxim~~ ^{maxim} ~~minuta~~ ^{minuta} ~~friabili~~ ^{friabili} ~~circundatis~~ ^{circundatis} ~~mixto~~ ^{mixto} ~~perforatis~~ ^{perforatis}. Vix lineam lat et longa.

1

1269 - 124 - *Syn. Fung.*



Sphaeria radicalis
Los
Salem.

Sphaeria radicalis
Salem
in herb. Linn. mus.

2

Sphaeria radicalis - *Schw.*

Salem

FIG. 1.—PHOTOGRAPH OF SCHWEINITZ'S MANUSCRIPT NOTES, WITH HIS DESCRIPTION OF *SPHAERIA RADICALIS*. FIG. 2.—SPECIMEN OF *S. RADICALIS* IN THE MOUNTED COLLECTION OF SCHWEINITZ, AS PREPARED BY MICHENER; ALSO ORIGINAL PACKET WITH SCHWEINITZ'S AUTOGRAPH LABEL.

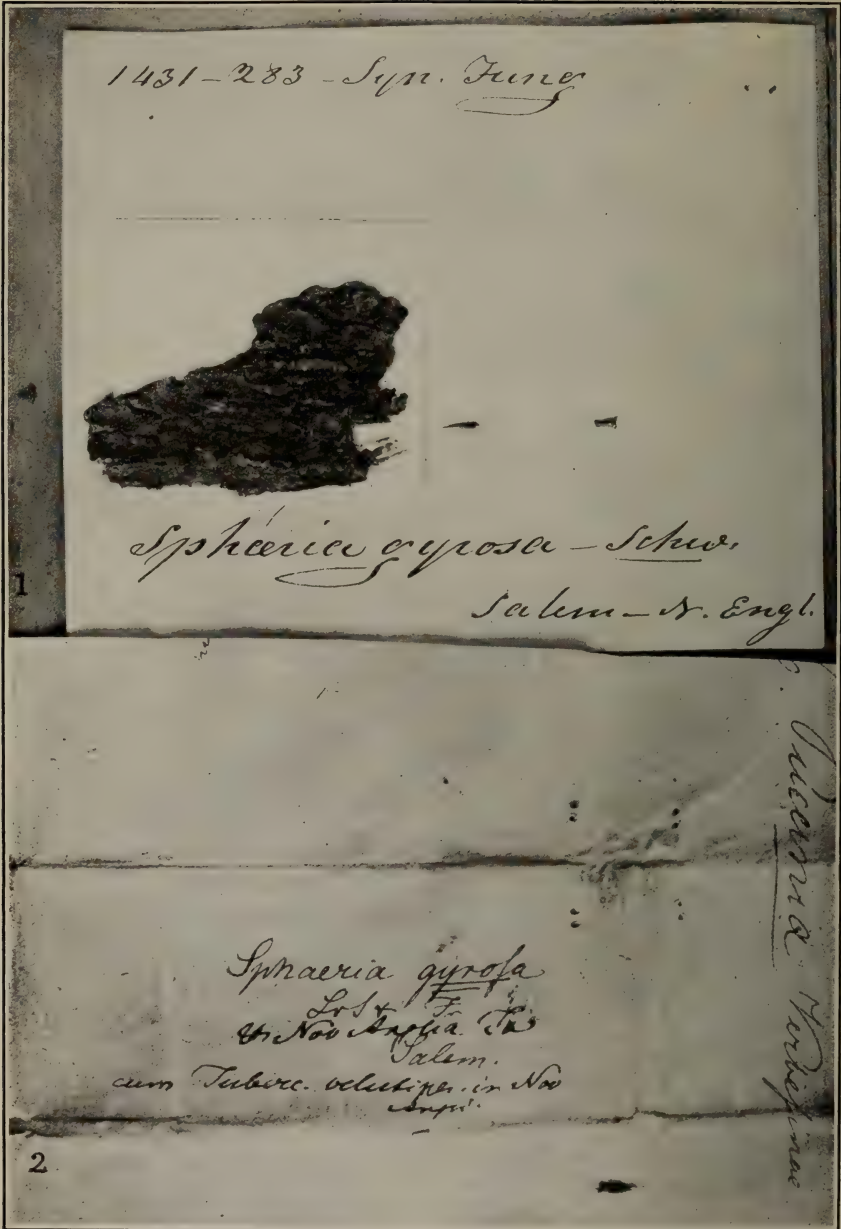


FIG. 1.—PHOTOGRAPH OF THE SPECIMEN IN SCHWEINITZ'S HERBARIUM MOUNTED BY MICHENER. NOT TRUE ENDOTHIA GYROSA BUT A NECTRIA. FIG. 2.—ORIGINAL PAPER PACKET IN WHICH SCHWEINITZ'S TYPE MATERIAL OF *E. GYROSA* WAS PRESERVED, WITH HIS AUTOGRAPH LABEL.



ENDOTHIA GYROSA GROWING ON THE RECENTLY CUT END OF A LIVING BRANCH OF FAGUS SP. NATURAL SIZE.



MYCELIAL FANS OF *ENDOTHIA PARASITICA* UNDER THE BARK OF *CASTANEA DENTATA*.

Illustration from Heald (39), by courtesy of I. C. Williams, Pennsylvania State Forestry Department.

SYNONYMS—Continued.

Perithecia—Continued.

Sphaeria radicalis Schw., 1832, *Fun. Am. Bor.*, p. 197.

Sphaeria radicalis Schw., Mont., 1834, in *Ann. Sci. Nat. Bot.*, s. 2, t. 1, p. 295.

Sphaeria (Diatrype) *radicalis* Fries, Currey, 1858, in *Trans. Linn. Soc. London*, v. 22, pt. 3, p. 272, pl. 47, fig. 89. p. p.

Valsa radicalis Ces. and De Not., 1863, in *Comm. Soc. Crittog. Ital.*, v. 1, p. 207.

Endothia radicalis (Schw.) Ces. and De Not., 1863, in *Comm. Soc. Crittog. Ital.*, v. 1, opp. p. 240.

Melogramma gyrosum L. R. and C. Tul., 1863, *Selecta Fung. Carpol.*, t. 2, p. 87. p. p. max.

Sphaeria (Diatrype) *radicalis* Schw., Currey, 1865, in *Trans. Linn. Soc. London*, v. 25, pt. 2, p. 244.

Endothia gyrosa (Schw.) Fekl., Sacc., 1882, *Syll. Fung.*, v. 1, p. 601. p. p.

Endothia gyrosa var. *rostellata* Sacc., 1882, *Syll. Fung.*, v. 1, p. 602.

Endothia radicalis (Schw.) Wint., 1887, *Pilze*, p. 803.

Endothia gyrosa Schw., Ell. and Ev., 1892, *No. Amer. Pyren.*, p. 552. p. p.

Endothia virginiana P. J. and H. W. And., 1912, in *Phytopathology*, v. 2, no. 6, p. 261.

Endothia gyrosa (Schw.) Fries, Clint., 1913, in *Conn. Agr. Exp. Sta. Rpt.*, 1911-12, p. 425.

Endothia pseudoradicalis Petri, 1913, in *Atti R. Accad. Lincei Rend. Cl. Sci. Fis., Mat. e Nat.*, s. 5, v. 22, sem. 1, fasc. 9, p. 654.

Endothia gyrosa (Schw.) Fekl., Höhnelt, 1913, in *Sitzber. K. Akad. Wiss. [Vienna], Math. Naturw. Kl., Abt. 1, Bd. 122, Heft 2*, p. 298.

TYPE SPECIMEN.—Sowerby in *Herb. Kew.* on *Castanea sativa*, New Forest, England. Coll. C. Lyell, Apr. 15, 1809.

PYCNIDIA.—Stromata cortical or subcortical, truncate conical to pulvinate, usually separate and gregarious, but frequently confluent, 0.75 to 3 mm. in diameter by 0.5 to 2.5 mm. high, compact, varying from light auburn to chestnut on the surface and capucine yellow to cadmium orange within; pycnidia consisting of simple or more or less complex and irregular chambers in the stroma, opening by an irregular pore or slit at the apex of the stroma; sporophores usually simple, sometimes branched near the base, cylindric to subclavate, 10 to 13 μ long, sometimes 24 to 30; pycnosporos oblong to rod-like, pale yellowish in mass, 3 to 5 by 1.5 to 2 μ , mostly 3.5 to 4 by 2 μ .

PERITHECIA.—Stromata the same or similar to those producing pycnidia; perithecia membranous, few to many, mostly 15 to 25, 300 to 400 μ in diameter, usually arising in the lower portion of the stroma, irregularly arranged in one to three layers, prolonged into slender necks which penetrate the stroma above and protrude usually from 300 to 600 μ , terminating in conical ostioles; asci oblong fusoid or subclavate, very short stipitate, 30 to 40 by 6 to 8 μ , mostly 30 to 35 by 7 μ , ascospores irregularly biseriate, oblong fusoid or subellipsoid, not constricted at the septum, hyaline with a thin gelatinous envelope, 6 to 10 by 3 to 4.5 μ , mostly 6.5 to 9 by 3 to 4 μ .

CULTURAL CHARACTERS.—Cultures one month old on white corn meal show a compact growth with a nearly smooth surface. The color ranges from light cadmium to empire yellow, and the medium becomes perilla purple. Pycnidia and spores usually appear a little later, forming large erumpent stromata which extrude thick masses of pycnosporos. The light mycelium with large

- pycnidial stromata and spore masses are distinguishing characters on this medium.

HOSTS.—America: Exposed roots and branches of *Q. alba*, *Q. coccinea*, *Q. marylandica*, *Q. prinus*, *Q. rubra*, *Q. velutina*, and *Castanea dentata*. Europe: Specimens examined, *Quercus pedunculata*, *Castanea sativa*, *Alnus glutinosa*, *Ulmus campestris*, *Carpinus betula*, and *Corylus* sp. Japan: *Castanea* sp. and *Pasania* sp. It is also reported on *Aesculus*, *Fagus*, and *Juglans* by Traverso.

TYPE LOCALITY.—New Forest, England.

GEOGRAPHICAL DISTRIBUTION.—America: Southern Pennsylvania and Ohio to South Carolina and northern Mississippi. Europe: Southern England, France, South Germany, and Switzerland to southern Italy and Transcaucasia. Asia: Japan.

ILLUSTRATIONS.—Sowerby, 1814, Col. Fig. Engl. Fungi, Sup., pl. 438; Currey, 1858, in Trans. Linn. Soc. London, v. 22, pt. 3, pl. 47, fig. 89 (2 upper spores); Ces. and De Not., 1863, in Comm. Soc. Crittog. Ital., pl. 3; Sacc., 1873, in Atti Soc. Veneto-Trentina Sci. Nat. Padova, v. 2, fasc. 1, pl. 14, fig. 63–65; Sacc., 1883, Gen. Pyren., pl. 6, fig. 6; Rühl., 1900, in Hedwigia, Bd. 39, pl. 2, fig. 10; Trav., 1906, in Soc. Bot. Ital. Fl. Ital. Cript., pars 1, v. 2, fasc. 1, p. 180, fig. 34; P. J. and H. W. And., 1913, in Penn. Chestnut Tree Blight Com. Bul. 4, p. 22, fig. 2, A and C; Clint., 1913, in Conn. Agr. Exp. Sta. Rpt., 1911–12, pl. 28, fig. b, e, h, and j; Petri, 1913, in Atti R. Accad. Lincei Rend. Cl. Sci. Fis., Mat. e Nat., v. 22, sem. 1, fasc. 9, p. 656, fig. 1–3.

EXSICCATI.—Pycnidia: Thüm. Myc. Univ., 769, on *Castanea*; Sacc. Myc. Ven., 670, on *Carpinus betula*; Sacc. Myc. Ven., 929, on *Castanea*. Perithecia: Fckl. Fun. Nass., 640, on *Ulmus campestris*; Erb. Critt. Ital., 986, on *Castanea*; Rab. Herb. Viv. Myc., 254, on *Castanea*.

Roum. Fun. Sel. Gal., 989, labeled *Endothia gyrosa* Schw. on beech is apparently young *Hypoxylon coccineum*.

The most important synonyms given here have already been discussed. Of the others the writers have examined the types or collections upon which the identifications were based. All the material of *Endothia* in the herbaria of Cesati, De Notaris, Fuckel, and Berkeley, as well as other smaller collections, has been carefully studied. *E. virginiana* And. and And. has been studied in cultures, as well as typical specimens from the authors of the species, and agrees in every particular with *E. fluens*.

Through the kindness of Dr. Petri a part of the type of his *E. pseudoradicalis* has been examined, but unfortunately no cultures could be obtained from the specimen. The writers have been unable to distinguish his specimen from forms of *E. fluens* which appear to show all the intermediate conditions of variation connecting it with typical *E. fluens*. The ascospores of *E. fluens* are more variable in size and shape than those of any other species of *Endothia* studied. After examining many specimens of this species from Europe, it does not seem possible at present to separate any of them. The case of *E. pseudoradicalis* can not perhaps be regarded as closed until more material of it has been collected and compared in culture. In fact, the slide from the type of *Sphaeria radicalis* Schw. shows ascospores of both the narrow and broad form. The photomicro-

graph, Plate XVII, fig. 9, shows an ascospore which agrees with Petri's description and figures.

ENDOTHIA FLUENS MISSISSIPPIENSIS S. and S. nov. comb.

SYNONYM:

Endothia radicalis mississippiensis Shear and Stevens in U. S. Dept. Agr., Bur. Plant Indus. Cir. 131, p. 4. 1913.

TYPE SPECIMEN.—No. 1782, on *Castanea dentata*, Blue Mountain, Miss., N. E. Stevens, Feb. 13, 1913. Deposited in Pathological and Mycological Collections, Bureau of Plant Industry.

CULTURAL CHARACTERS.—Cultures one month old on white corn meal show a compact, rather uniform surface, the color of the mycelium varying from cadmium orange to xanthine orange. This variety is distinguished from the species by the color of its mycelium, by the numerous small pycnidia thickly scattered over the surface of the culture, and by the lack of any purple color in the medium.

HOSTS.—*Castanea dentata*, *Quercus alba*, and *Q. velutina*.

GEOGRAPHICAL DISTRIBUTION.—Northern Mississippi, Kentucky, Tennessee.

COLLECTIONS EXAMINED.—On *Castanea dentata*: No. 1706 A. pycnidia, Corinth, Miss., T. E. Snyder; no. 708, pycnidia, Dumas, Miss., T. E. S.; no. 1782, ascospores, Blue Mountain, Miss., N. E. S.; no. 1806, ascospores, Blue Mountain, Miss., N. E. S. On *Quercus*: No. 1989, pycnidia, Danville, Ky., N. E. S.; no. 1995, pycnidia, Danville, Ky., N. E. S.; no. 2032, pycnidia, Lexington, Tenn., N. E. S.; no. 2255, pycnidia, Sardis, Miss., S. and S.

No morphological characters have yet been found to distinguish this variety. It is therefore separated on its cultural characters, which are marked and constant. The plant was first collected by T. E. Snyder, of the Bureau of Entomology.

ENDOTHIA LONGIROSTRIS Earle, 1900, in Muhlenbergia, v. 1, no. 1, p. 14.

SYNONYM:

Perithecia: *Diatrype radicalis* (Schw.) Fries, Mont., 1855, in Ann. Sci. Nat. Bot. 4, t. 3, p. 123. Not Schw.

TYPE SPECIMEN.—No. 4340. A. A. Heller, Plants of Porto Rico. In Herb. N. Y. Bot. Garden.

PYCNIDIA.—Stromata corticular, erumpent, gregarious, sometimes confluent, 1 to 3 mm. in diameter, subcoriaceous, surface orange rufous to chestnut, interior zinc orange; pycnidia consisting of irregular labyrinthiform cavities opening by a single large pore or irregular rupture at the apex of the stroma; sporophores slender, somewhat tapering upward, mostly 8 to 10 μ long; pycnospores oblong elliptic, hyaline or yellowish in mass, when expelled forming a stout spore horn or tendril, colored like the stroma on the outside, 2 to 4 by 1 to 1.5 μ .

PERITHECIA.—Stromata the same as those producing pycnidia, but larger and frequently confluent, forming linear series in crevices in the bark; perithecia arising usually at the base of the pycnidial stroma, mostly 3 to 10 in the separate stromata, membranous, 300 to 400 μ in diameter, mostly in a single irregular series, prolonged into long necks, 1.5 to nearly 1 cm. long, sec. Earle, internally black, externally same color and structure as the stroma; ostiole acute; asci oblong cylindric to fusiform, 25 to 35 by 5 to 7 μ , mostly 30 by 6 μ ; ascospores overlapping uniseriate to irregularly biseriate, hyaline, ovoid to ovoid elliptical, 6 to 8.5 by 3 to 4 μ , mostly 7 to 7.5 by 3 to 3.5 μ .

CULTURAL CHARACTERS.—Cultures one month old on white corn meal have a uniform cadmium orange to xanthine orange color. The entire surface is covered with a compact growth, irregularly ridged. Tiny mars orange spore masses are scattered irregularly over the surface. Cultures of this species closely resemble *E. fluens mississippiensis* on this medium, being distinguished by the smaller and much less numerous spore masses. The medium is changed to amber brown just below the mycelium, shading into mars yellow; whereas, in the case of *E. fluens mississippiensis* the color of the medium is very little changed.

TYPE LOCALITY.—"Calcareous hills east of Santurce, Porto Rico, altitude 10 ft."

GEOGRAPHICAL DISTRIBUTION.—Porto Rico and French Guiana.

EXSICCATI.—Pycnidia and perithecia: Heller, Plants of Porto Rico, no. 4340.

This species, which appears to be subtropical or tropical in its range, is known at present from only three collections, the type collection from Porto Rico, a collection by Prof. N. Wille, No. 816, Porto Rico, distributed by the New York Botanical Garden, from which the cultures were obtained; and one made by Leprieur, No. 392, in French Guiana, and determined by Montagne as *Diatrype radicalis* (Schw.). A specimen of this collection apparently labeled by Montagne and preserved in the Delessert Herbarium at Geneva has been examined and found to agree with the type material of *E. longirostris*. It is readily distinguished from *E. tropicalis* by its smaller ascospores and pycnospores, and from *E. fluens* by its narrower and more acute ascospores and the long, slender necks of the perithecia.

ENDOTHIA TROPICALIS Shear and Stevens sp. nov.

SYNONYMS:

Diatrype gyrosa Berk. and Broome, 1875, in Jour. Linn. Soc. [London], v. 14, p. 124.

Nectria gyrosa Berk. and Broome, 1877, in Jour. Linn. Soc. [London], v. 15, p. 86.

Cryphonectria gyrosa (Berk. and Broome) Sacc., in Syll. Fung., v. 17, p. 784. 1905.

Endothia gyrosa (Schw.) Fekl., Höhnelt, 1909, in Sitzber. K. Akad. Wiss. [Vienna], Math. Naturw. Kl., Abt. 1, Bd. 118, Heft 9, p. 1480.

TYPE SPECIMEN.—No. 2807 S. and S., on *Elaeocarpus glandulifer*, Hakgala, Ceylon, Coll. T. Petch, August, 1913.

PYCNIDIA.—Stromata corticular, pustular to pulvinate, usually gregarious or scattered, rarely confluent, 1 to 5 mm. in diameter, early becoming friable, orange chrome when fresh to sanford brown when old and weathered; pycnidia consisting of numerous irregular cavities in the stroma; sporophores mostly simple, clavate, tapering above, 6 to 10 μ long; pycnospores continuous, oblong to cylindric, very variable in size and shape, pale yellowish in mass, 3.5 to 7 by 1.5 to 2.5 μ .

PERITHECIA.—Stromata the same or similar to those bearing pycnidia; perithecia black, membranous, collapsing when dry, 5 to 50 or more in a stroma; 250 to 500 μ diameter, irregularly arranged in one to three layers, bearing slender necks which penetrate the stroma and project 0.25 to 1 mm., terminating in acute ostioles; asci oblong or subclavate, nearly sessile, 40 to 50 by 7 μ ; ascospores irregularly biseriate, subelliptical, obtuse, not constricted at

the septum, hyaline with a gelatinous envelope, 7.5 to 10.5 by 3.5 to 5 μ , mostly 8 to 10 by 4 to 4.5 μ .

CULTURAL CHARACTERS.—Cultures one month old on white corn meal show small numerous, thickly scattered pycnidia and spore masses very similar to *E. parasitica*. The mycelium is orange buff to apricot orange. This species differs from *E. parasitica* in culture, chiefly in the brighter color of its mycelium.

HOST.—Rotten logs and stumps of *Elaeocarpus glandulifer*.

TYPE LOCALITY.—Hakgala, Ceylon.

GEOGRAPHICAL DISTRIBUTION.—Only known from Ceylon at present. One other collection of this species, No. 290 G. H. K. T. [Thwaites], N. Eliya, Ceylon, 6,000 feet, has been examined in the Kew Herbarium.

Through the kindness of Mr. T. Petch, of Peredeniya, the writers have received two large collections of this fungus. Some of the material was in a living condition and enabled the writers to obtain pure cultures for comparison with the other species of *Endothia*. This species is closely related to *E. parasitica*, but is readily separated by its larger ascospores and larger and more variable pycnospores and its nonparasitic habit.

ENDOTHIA PARASITICA (Murr.) P. J. and H. W. And., 1912, in *Phytopathology*, v. 2, no. 6, p. 262

SYNONYMS:

Diaporthe parasitica Murrill, 1906, in *Torreyia*, v. 6, no. 9, p. 189.

Valsonectria parasitica Rehm, 1907, *Asc. Exs.*, no. 1710.

Valsonectria parasitica Rehm, 1907, in *Ann. Mycol.*, v. 5, no. 3, p. 210.

Endothia gyrosa var. *parasitica* Clint. 1912, in *Science*, n. s., v. 36, no. 939, p. 913.

Endothia gyrosa (Schw.) Fekl. Höhnelt, 1909, in *Sitzber. K. Akad. Wiss. [Vienna]*, Math. Naturw. Kl., Abt. 1, Bd. 118, Heft 9, p. 1480.

TYPE SPECIMEN.—Herbarium N. Y. Bot. Garden, on *Castanea dentata*, Bronx Park, New York City, Nov. 26, 1905, Coll. W. A. Murrill.

PYCNIDIA.—Stromata corticular, slightly erumpent to truncate conical, usually separate and gregarious, frequently confluent in more or less linear series especially in old rimose bark, 0.75 to 3 mm. in diameter by 0.5 to 2.5 mm. high, varying from capucine yellow when young to auburn when old and weathered; pycnidia consisting of irregular cavities in the stroma, 100 to 300 μ in diameter; sporophores mostly simple, subclavate, acute at the apex, usually 12 to 20 by 1.5 μ , more elongated filaments sometimes reaching 50 μ or more being frequently found among the normal sporophores; pycnospores, oblong to cylindric, rounded at the ends, 3 to 5 by 1.5 to 2, mostly 3.5 to 4.5 by 1.5 to 2 μ , pale yellowish in mass under the microscope; old spore tendrils coral red.

PERITHECIA.—Stromata the same or similar to the pycnidial stromata; perithecia dark, membranous, globose to flask shaped, collapsing when dry, 5 to 50 or sometimes more in a stroma, 300 to 400 μ in diameter, irregularly arranged in one to three layers and bearing slender necks projecting above the stroma, 300 to 600 μ , colored like the stroma on the outside and terminating in acute ostioles; asci oblong elliptical to subclavate, nearly sessile, 30 to 60 by 7 to 9 μ , mostly 40 to 50 by 8 μ ; ascospores irregularly biseriata, ellipsoid, obtuse, sometimes constricted at the septum, hyaline, with a gelatinous envelope, 7 to 11 by 3.5 to 5 μ , mostly 8 to 9 by 4 to 4.5 μ .

CULTURAL CHARACTERS.—Cultures one month old on white corn meal have a white to pale orange yellow surface mycelium and produce numerous minute

pycnidia and pale yellow spore masses. It is distinguished from its nearest relative, *E. tropicalis*, by the lighter color of the mycelium.

HOSTS.—*Castanea dentata*, *C. sativa* and cult. vars., *C. pumila*, *Castanea mollissima* from China and *Castanea japonica* from Japan, *Quercus alba*, *Q. prinus*, *Q. velutina*, *Acer* sp.

It is also reported on *Rhus typhina* and *Carya ovata* by Anderson and Rankin.

TYPE LOCALITY.—Bronx Park, New York City.

GEOGRAPHICAL DISTRIBUTION.—Southern Maine to Ohio and southward to North Carolina; also Missouri, Iowa, Nebraska, British Columbia, China, and Japan.

ILLUSTRATIONS.—Murrill, 1908, in *Torreya*, v. 8, no. 5, p. 111, fig. 2; Petri, 1913, in *Atti R. Accad. Lincei, Rend. Cl. Sci. Fis., Mat. e Nat.*, s. 5, v. 22; sem. 1, fasc. 9, p. 656, fig. 4; Heald, 1913, in *Penn. Chestnut Tree Blight Com. Bul.* 5, pl. 13; Clint. 1913, in *Conn. Agr. Exp. Sta. Rpt.*, 1911/12, pl. 28, fig. c, f, i, and k; P. J. and H. W. And., 1913, in *Penn. Chestnut Tree Blight Com. Bul.* 4, p. 22, fig. 2, B and D; P. J. And. and Rank., 1914, in *N. Y. Cornell Agr. Exp. Sta. Bul.* 347, p. 562, fig. 89.

EXSICCATI.—Pycnidia and perithecia: Rehm, Asc., 1710; Wilson and Seaver, Asc. and Low. Fun., 3; Bart. Fun. Col., 2926; all on *Castanea dentata*.

This species is closely related in its morphological characters to all the species of section 2 of the genus. It is most likely to be confused with *E. fluens*, but shows constant differences, though slight, in size and shape of ascospores. They are predominantly broader and more uniform in shape, as shown by the table of measurements on page 35. In its active parasitic condition on *Castanea* it can always be distinguished by the presence of the mycelial "fans" in the inner bark, as shown in Plate VIII. It has been confused with *E. gyrosa* through an erroneous identification of that species.

MORPHOLOGY AND DEVELOPMENT.

MYCELIUM.

By far the most striking mycelial character is the production by *E. parasitica* of yellow or buff fan-shaped formations of mycelium in the cambium and bark of the host. These "fans" vary from 1 mm. to 1 cm. or more in width, and are composed of radiating hyphæ closely pressed together to form a continuous layer. (Pl. VIII.) So constant are these mycelial fans in their occurrence and so characteristic in their appearance that they furnish the most reliable field character for distinguishing *E. parasitica* from related species and may quite properly be regarded as a specific character when the fungus is growing in living trees.

Anderson and Anderson (2, p. 204) first called attention to the fact that these fan-shaped formations of mycelium are absent from *E. fluens*. Rankin (62, p. 248) states that when the fungus grows saprophytically or while the tree is dormant these fans are not produced. Anderson and Rankin (6, p. 565) report that in inoculations

on *Quercus alba* and *Q. prinus*, *E. parasitica* produced the typical mycelial fans.

Anderson (1, p. 14) considers that the occurrence of these fans is associated with the parasitic habit of the fungus. In his opinion single hyphæ do not possess the power of penetrating the living cells, but the fungus grows on the injured and dead cells about a wound until a quantity of mycelium is accumulated, when it "*en masse* pushes through the living tissues of the bark." This view is also held by Keefer (45, p. 193), who adds that "the action of the advancing mycelial mats seems to be physical rather than chemical, and the cells are mechanically broken to pieces."

Rankin, however, states (62, p. 248) that "The host cells, just in advance of the edges of the fan, are disintegrated and form a distinct gelatinous band, which can be seen with the naked eye." This observation suggests to the writers that some toxic or enzymatic action upon the cells of the host probably occurs before the cells are actually invaded by the fungus hyphæ. Careful investigation of this point should go far toward determining the causes of the parasitism of this fungus. Whatever the cause or function of these fans, they are very characteristic, and the writers have found them invariably in diseased material of *Castanea* in America, as well as in that from China and in two specimens of *E. parasitica* on *Quercus*.

A similar mycelial formation, fanlike in form,¹ is produced by *Armillaria mellea* in the bark of roots attacked by this fungus. Excellent specimens of the *Armillaria* mycelial fans have been presented to the writers by Prof. Wm. T. Horne, of the University of California.

STROMATA.

Under the name *Melogramma gyrosum*, in which they included specimens of both *Endothia gyrosa* and *E. fluens*, the Tulasnes (83, pp. 87-89) described the structure of *Endothia* in some detail. Their description was based chiefly on abundant local material of *E. fluens* collected on *Carpinus betulus* L. during several years, but they also used material sent by Guepin from western France, pycnidial material on chestnut from Italy, American material sent by Schweinitz to Brongniart and preserved in the Paris Museum, and specimens from Carolina sent by Berkeley. According to the Tulasnes (83, p. 87)² the stromata are "developed singly and emerge gradually as so many scattered points with fibers radiating in all directions, soon swell into a yellowish cone, rupture the epidermis above them,

¹ Since this manuscript was completed a very similar mycelial formation has come to the writers' attention. As figured by Nowell (50), pl. 1, *Rosellinia pepo*, when growing under the bark of lime trees, forms mycelial fans resembling those of *Endothia parasitica*.

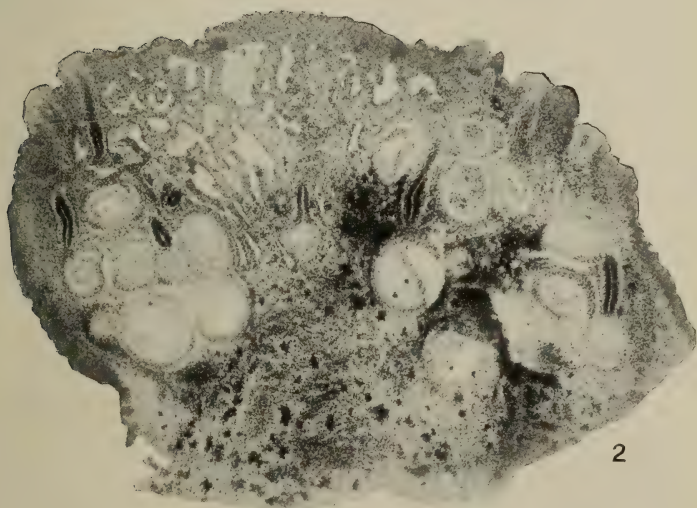
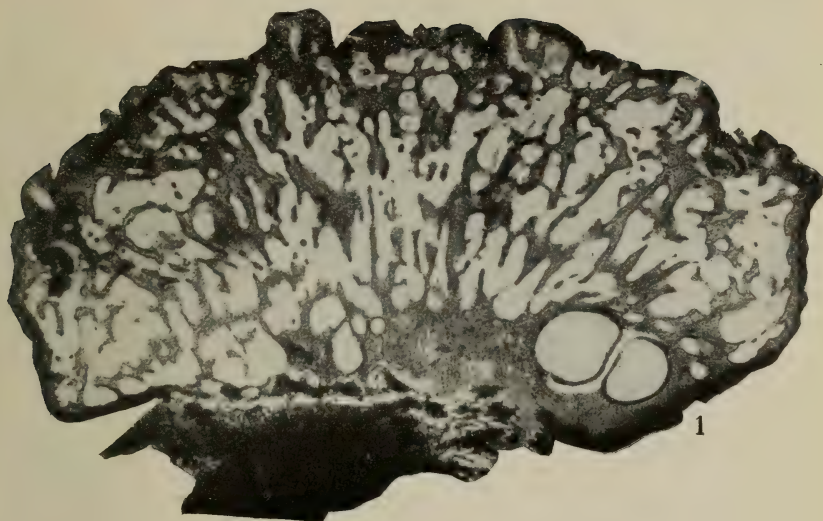
² The portions in quotations are rather free translations of the authors' Latin.

and put forth a very blunt apex. All are composed of a corky, parenchymatous, very dense, soft yellow material. The mature ones attain a diameter of 3 to 4 millimeters and a height of 1 to 2 millimeters, and on the somewhat reddish, and finally rusty red to yellow top, they are marked by black points, the ostioles." The Tulasnes observed that before the stromata reached their full size the pycnidial cavities were formed within them, sometimes "widely open," sometimes "narrow labyrinthine," and that through one or many openings in the top of the pycnidia, the long, twisted, orange tendrils, composed of mucus, and innumerable thin linear spores were expelled. "Perithecia are developed chiefly in stromata destitute of spermogonia, or more often with only a few * * * they arise very abundantly and irregularly, some barely buried in the yellow corklike substance, others lower down and seemingly located in the bark of the host itself."

Although the Tulasnes included all their material under a single species, they noted that the pycnidial stromata of the American specimens (really *Endothia gyrosa*) differed considerably from the European (*E. fluens*). In describing the former, they say (83, p. 88) "The American fungus is said to grow in the bark of *Fagus* and *Juglans* * * * as a whole it abounds with numerous, very small spermatia. Wherefore if it is very thinly sectioned, the pieces, examined with a compound microscope, show cavities just as if you had before your eyes the smallest *Gautieria* or *Balsamia*." The Tulasnes do not try to distinguish definitely between stroma and mycelium, but merely state that the stromata develop within the mycelium.

Ruhland (67), who was the next writer to discuss the morphology of a species of *Endothia*, defines the various portions of the fungus body in detail. According to his definition (p. 16) a "stroma (in distinction from mycelium) is the sum total of that part of the vegetative portion of the fungus body, which, without serving exclusively for absorption, takes part in the formation of the fruit body." He sets aside Fuisting's (36, p. 185) division of the fungus body into an epistroma and a hypostroma, as essentially nothing but the distinction of "conidial layers" and "perithecial stroma."

Ruhland divides the fungus body into an ectostroma and an entostroma. The ectostroma grows "on the upper surface of the parenchyma of the bark, between it and the periderm, and is composed of a generally wide-lumened plectenchyma which does not possess the power of absorption." This portion has the following functions: "The formation of the conidia, the opening and breaking off of the periderm, and the stimulation of the development of the entostroma." The entostroma, on the other hand, according to Ruhland, "lives in the parenchyma of the bark, and while young is in a high degree



ENDOTHIA GYROSA. VERTICAL SECTIONS OF STROMATA ON BEECH. $\times 32$.

FIG. 1.—SHOWING NUMEROUS PYCNIDIAL CAVITIES AND TWO MATURE PERITHECIA.
FIG. 2.—SHOWING MATURE PYCNIDIA AND PERITHECIA SIDE BY SIDE.

Except where otherwise indicated, the photomicrographs of stromata are from unstained sections cut with a freezing microtome.

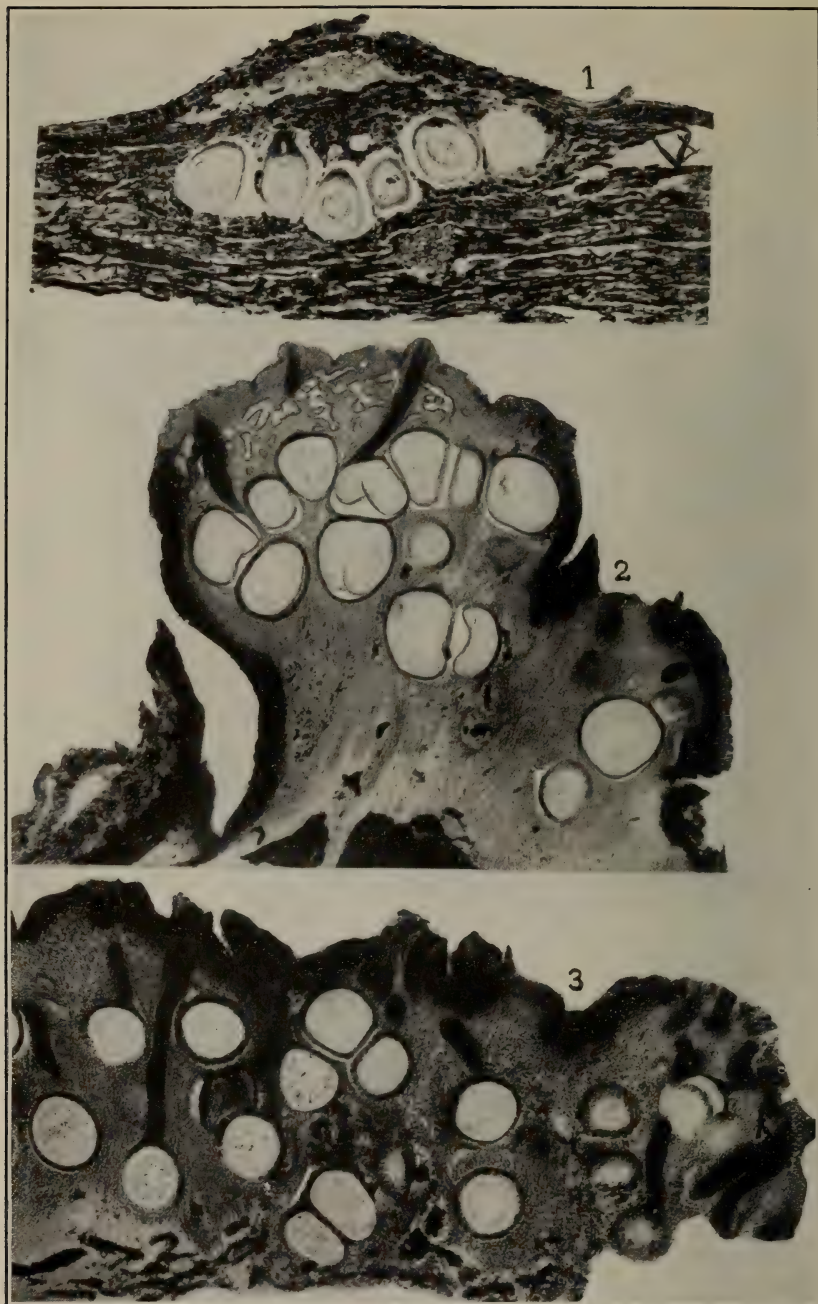
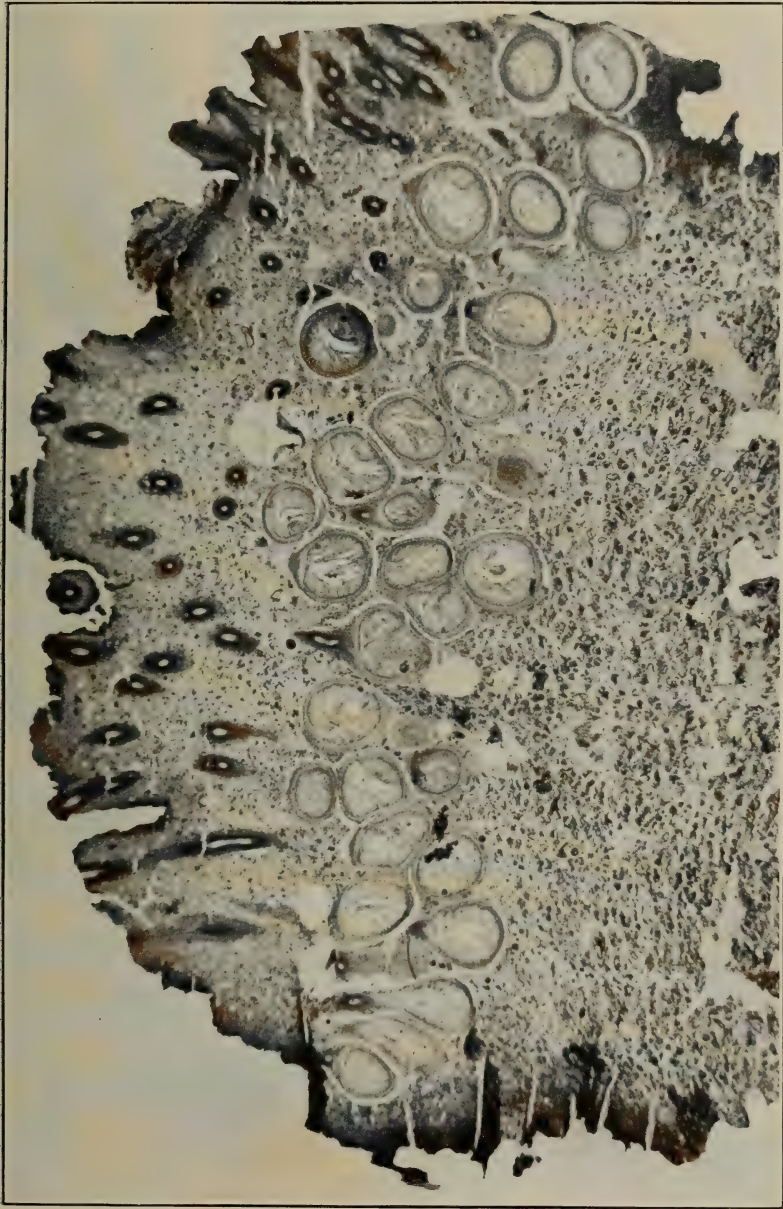


FIG. 1.—*ENDOTHIA FLUENS*. VERTICAL SECTION OF A STROMA FROM ITALY, SHOWING YOUNG PERITHECIA IN A SINGLE LAYER. $\times 49$. FIG. 2.—*ENDOTHIA GYROSA*. VERTICAL SECTION OF A STROMA ON BEECH, SHOWING MATURE PYCNIDIA WITH MATURE PERITHECIA BELOW THEM. $\times 32$. FIG. 3.—*ENDOTHIA GYROSA*. VERTICAL SECTION OF A PORTION OF A LARGE STROMA, SHOWING PERITHECIA IRREGULARLY ARRANGED IN SEVERAL LAYERS.



ENDOTHIA SINGULARIS. VERTICAL SECTION OF A STROMA, SHOWING PERITHECIA ONLY. $\times 32$.
Paraffin section stained with Bismarck brown.



ENDOTHIA SINGULARIS. VERTICAL SECTION OF A STROMA, SHOWING BOTH PYCNIDIA AND PERITHECIA. X 32.
Paraffin section stained with Bismarck brown.

capable of absorption, a power which it retains relatively permanently." In addition to its absorptive function the entostroma forms the pseudoparenchymatic cover for the perithecial walls.

Ruhland studied herbarium material from the Royal Botanic Museum of Berlin and specimens from Saccardo and Cesati, and described it under the name of *Endothia radicalis* (Schw.) Fr. (*E. fluens* of the present writers). He distinguishes an ectostroma, shaped like a truncated cone, consisting of fine, thin-walled hyphæ, so closely interwoven that the whole structure has a comparatively firm quality. Among these hyphæ are crystals of calcium oxalate. As soon as this ectostroma breaks through the bark there is formed near the middle a short-lived 1-chambered pycnidium. Below this ectostroma (height 0.5 to 0.6 mm., diameter 0.7 to 1 mm.) the entostroma grows out as a mycelium through the upper portion of the bark. Ruhland says, "The entostroma with us does not produce perithecia, but remains wholly mycelial." He studied the perithecial stage in Cesati's specimens, however, and concludes that the perithecia originate without much change in the size of the entostroma and at a considerable distance, about 1 mm., below the ectostroma. The long necks then penetrate through the overlying entostroma and into the ectostroma to the base of the now functionless pycnidia. The upper portion of the ectostroma is then quickly killed and thrown off.

Pantanelli briefly described the stromata of the genus *Endothia*, and pointed out several morphological characters which he considers distinctive of *E. parasitica* in contrast to *E. fluens*. Aside from spore characters, which will be discussed later, Pantanelli (60, p. 870) considers that *E. parasitica* is characterized by numerous stromata, at first embedded in the bark, finally free; by pycnidial cavities numerous and irregularly arranged in various planes in the stromata deep in the bark; pycnidial stromata 1.1 to 1.2 mm. in height and 2.1 to 2.2 mm. in diameter; ascogenous stromata, height 1.8 to 2 mm., length 2.5 to 3.4; width, 3 to 3.2 mm.; perithecia arranged in two or three layers; necks of perithecia averaging 1.25 mm., with inconspicuous ostioles; walls of the perithecia uncolored or light brown.

Endothia fluens, on the other hand, has isolated stromata, chiefly outside the bark; pycnidia aggregated, regularly arranged in a single superficial series; pycnidial stromata, height 0.4 to 0.5 mm., diameter 1.1 to 1.3 mm.; ascogenous stromata, height 1.1 to 1.4 mm., length 2.5 to 3.2 mm., width 1.2 mm.; perithecia arranged in a single row; necks of perithecia averaging 0.45 mm.; ostioles prominent; walls of the perithecia black.

Anderson (1, pp. 17-24) described the development of the fructifications of *Endothia parasitica* in detail. He studied the growth of

the pycnidia in pure culture and made sections of perithecial stromata growing on bark.

According to Anderson, the pycnidium originates as a mass of densely intertwined hyphæ, in the center of which numerous pycnospores are cut off. The crowding of these spores increases the size of the pycnidial cavity and crowds the outer hyphæ together to form a sort of wall. The ostiole is formed in the top by the loosening of the hyphæ. The stroma always starts as a loose growth of hyphæ around the pycnidium. It does not precede, but follows the first stages in the development of that organ. A fluffy growth of light-yellow mycelium surrounds the pycnidium and covers it over. If these are embedded and sectioned, they will be found to contain a loose tangle of undifferentiated hyphæ surrounding a central pycnidium. But as soon as the cork layer is broken the stroma undergoes a change. There is a rapid increase in size and at the same time a differentiation of the cells at the tips of those branches which reach the exposed surface. These cells now become shorter and thicker, acquire heavier walls, and are densely crowded together, so that in cross section they appear as a pseudoparenchymatous tissue. The layer thus formed covers all the exposed surface of the stroma and also grows up around the necks of the perithecia. The stroma increases very rapidly in size and a mass of stromatic tissue is formed beneath the pycnidia, which are thus pushed out through the cork layer into the periphery. The primordia of the perithecia are formed usually in the tissues of the bark below the base of the original pycnidium, but at times are formed well up in the stroma. Usually 15 to 30 perithecia mature in a stroma.

According to the writers' observations, the Tulasnes' description (83, pp. 87-89) is substantially correct so far as it goes. They, of course, placed pycnidial material of *Endothia gyrosa* in the same species with *E. fluens*, but, as already noted, they observed the difference in the structure of the stromata and aptly compared the pycnidial stroma of *E. gyrosa*, as seen in section, to a Gautieria.

The division of the stroma into ectostroma and entostroma made by Ruhland (67, p. 16) has, at least in the species of *Endothia*, no validity whatever. While it is true that pycnidia usually occur in the portion of the stroma first developed and perithecia often develop below them, this is by no means an invariable rule; and while stromata are developed which contain only pycnidia, other stromata apparently produce only perithecia or no spores whatever. Certainly no portion of the stroma can be distinguished which invariably produces only perithecia or only pycnidia. On the contrary, there is great variation in the relative position and time of appearance of the two types of fruiting structures. Also, while

the pycnidial cavity is sometimes small and simple, as described by Ruhland, it is more often large and much convoluted. (See Pls. XV and XVI.)

While the writers, of course, agree with Pantanelli (60) that *Endothia parasitica* and *E. fluens* are distinct species, many of the stromatic characters which he describes are so variable as to be unreliable. In an examination of a large number of specimens the writers have been unable to find any constant difference in the arrangement or structure of the pycnidial stromata. This seems to depend chiefly in both species on the character of the bark and the moisture conditions. As to size, while the stromata of *E. parasitica* examined average somewhat larger than those of *E. fluens*, the range of the pycnidial stromata is about the same in the two species, varying from 0.4 to 2 mm. in height and from 0.2 to 3 mm. in length.

The ascogenous stromata are also very variable in size. Those measured by the writers varied in height from 0.5 to 2 mm. in *Endothia parasitica* and from 0.5 to 2.3 mm. in *E. fluens*. In width the perithecial stromata were from 1 to 2.5 mm. in both species, while there is apparently no method for determining their length, since on thick-barked trees continuous narrow masses of perithecial stromata are often formed in the crevices of the bark. These stromatal masses frequently extend from 5 to 10 cm., and while they are in all probability formed by the fusion of several stromata there is no way of determining how far each extends.

The arrangement of the perithecia mentioned by Pantanelli (60) as a specific character seems to depend on the nature of the bark of the host. When the bark is thin and easily ruptured the stromata tend to spread out so that the perithecia occur in a single layer, while if the bark is thick and deeply ridged the stromata are thicker and the perithecia occur in two or more layers. That this is not a specific character is clearly shown by Plate XVI. Figures 1 and 3 of this plate show a stroma of *E. parasitica* and of *E. fluens*, respectively, both with three layers of perithecia, while Plate XVI, figure 2, and Plate X, figure 1, show stromata of both species with perithecia arranged in a single layer.

Although, as already indicated, the stromata of each species are very variable, they are sufficiently distinct so that the native American species may readily be distinguished in the field.

The stromatic characters of *Endothia gyrosa* and *E. singularis* are much more distinct than those of the other species. The stromata of *E. gyrosa* are erumpent, irregularly subglobose, with a rather roughened surface. They are usually from 1.5 to 2 mm. in height and vary from 1.5 to 3 mm. in width. The stromata of *E. singularis* are much larger than those of any other species of *Endothia*, being

usually from 2 to 4 mm. in length and 3 to 5 mm. or more in diameter. They are decidedly erumpent, rather regular, and subglobose in outline. The contents of the stromata are brick red in color and are very powdery when old.

The stromata of *Endothia fluens*, *E. fluens mississippiensis*, and *E. parasitica* resemble each other so closely that the species are practically indistinguishable on this basis. All these species are characterized by partially embedded, confluent stromata which vary greatly in outline, depending on the nature of the bark of the host. As already stated, they vary from 0.4 to 2 mm. in height and from 0.7 to 5 mm. or more in length where confluent. *E. tropicalis* and *E. longirostris* resemble this group in their stromatic characters.

Pycnidia.—The pycnidia of *Endothia gyrosa* and *E. singularis* are very distinctive also. The pycnidial cavities of *E. gyrosa* are narrow and so irregularly convoluted that in a section of the stroma the cavities vary in width from 0.03 to 0.3 mm., averaging about 0.15 mm. On the whole, however, they are much narrower than those of *E. fluens* or *E. parasitica*. A section of a pycnidial stroma of *E. gyrosa* shows numerous irregular, rounded to elongate chambers separated by narrow walls. The pycnidial cavities of *E. singularis* (Pl. XIII) are minute, 0.03 mm. in diameter, nearly spherical, evenly distributed through the stroma and separated at first by comparatively thick walls, which disintegrate and become powdery when the stroma is old.

So far as the writers have been able to determine, the "tendrils" of pycnosporos so characteristic of *Endothia fluens* and *E. parasitica* are not formed in either *E. gyrosa* or *E. singularis*. Mature pycnidial stromata of *E. gyrosa* when placed in a moist chamber exude numerous droplets containing spores and scattered well over the surface of the stromata. The writers have been unable to produce any such change by placing the pycnidial stromata of *E. singularis* in moist chambers, and it seems probable that the pycnosporos of *E. singularis* are set free by the breaking down of the outer walls of the stromata. As already mentioned, the inner partitions are friable, so the spores are readily scattered by the wind.

The pycnidial cavities of *Endothia fluens* and *E. parasitica*, and apparently all the other species of this section of the genus, vary from 0.2 to 0.3 mm. or more in diameter and may consist of a single chamber rather regular in outline (Pl. XIV, fig. 1) or of an irregular cavity consisting of many chambers (Pl. XV, fig. 3) more or less completely separated from one another. These species differ from *E. gyrosa* in that the pycnosporos are usually discharged through a single opening near the top of the stroma and emerge in a single twisted tendril.

Development of the stromata.—The writers have not followed the development of the stromata in culture, but an examination of numerous sections of *Endothia singularis*, *E. gyrosa*, *E. fluens*, and *E. parasitica* and a study of the three latter species under field conditions on various hosts shows that their development is by no means as uniform as indicated in Anderson's description (1).

According to Anderson, the pycnidium develops first, and about the young pycnidium the stroma is quickly formed, while the perithecia arise later, usually in the lower portion of the stroma. This may perhaps be considered the typical course of development, and pycnidia are often found above the perithecia, but all variations occur. A large stroma may be developed without a sign of a pycnidium (Pl. XV, fig. 2). In some cases there is a considerable portion of the stroma above the pycnidial cavity (Pl. XIV, fig. 2), or the pycnidial cavities may be surrounded by a thick stroma (Pl. XIV, fig. 4, and Pl. XV, fig. 1). Sometimes, on the other hand, they are large and irregular, with little stroma (Pl. XV, fig. 3).

The perithecia by no means uniformly arise below the pycnidia, but the two often occur side by side in the same stroma (Pl. IX, fig. 2; Pl. XIV, fig. 3; and Pl. XII). Sometimes, even, the perithecia are above the pycnidia (Pl. XIV, fig. 2). There seems to be no constant relation either as to the relative number of pycnidia or of perithecia in a single stroma. Sometimes the pycnidial portion is much larger (Pl. IX, fig. 1); sometimes the perithecia predominate (Pl. X, fig. 2); and sometimes the two portions are practically equal (Pl. XII).

A like variability apparently occurs in the sequence of the fruiting bodies. As the figures show, the pycnidia sometimes develop after the perithecia; the reverse order is frequent; while in several sections (Pl. XII, and Pl. XIV, fig. 3) the two types of fruiting bodies were side by side and were producing mature spores abundantly at the same time. Just what factors determine the production of each type of spore or prevent or delay spore production is unknown. It seems probable, however, that climatic influences may prevent the development of ascospores in many cases. The action of climate may be very indirect, however, for no ascospores of any species have yet been obtained in artificial cultures, though *Endothia fluens*, *E. fluens mississippiensis*, *E. tropicalis*, and *E. parasitica* produce pycnosporangia abundantly on a variety of media. Certainly, climatic factors would not account satisfactorily for the fact that pycnidia and perithecia are produced at the same time in adjacent stromata, or even in different parts of the same stroma.

The size of the perithecia is rather uniform in the various species (Pl. X, fig. 3, and Pls. XI and XVI), being about 0.35 mm. in diameter. They are typically globose to pyriform, but are usually more or

less irregular on account of crowding. This pressure may be so great as to produce almost any shape, and such perithecia sometimes measure 0.5 mm. in the greatest diameter and 0.1 mm. in the shortest.

SPORE MEASUREMENTS.

The spore measurements recorded here were made by Miss Tiller. In the case of dried specimens, the spores were first soaked for three hours in lukewarm water and then mounted in the potassium-glycerine-copper medium, prepared according to the following formula:

1 part 2 per cent potassium acetate in water.

1 part 40 per cent glycerine in alcohol.

Copper acetate sufficient to color.

In the case of fresh specimens they were mounted directly in the same medium. The measurements were made with a Zeiss filar eyepiece micrometer and a Zeiss 3 mm. 1.40 N. Ap. oil-immersion objective. Only approximate accuracy is claimed for these results, on account of the difficulty of overcoming the motion of the spores in a fluid medium. The results are, however, believed to be fairly comparable, as practically all were measured under the same conditions and treatment, and the margin of error is presumably rather uniform. The differences in size of pycnospores do not appear to be sufficient, however, to furnish diagnostic character for most of the species.

The number of measurements of ascospores of *Endothia fluens* and *E. parasitica* is much larger than of the other species, as special attention was first given to these two species on account of their great similarity. In order to make the measurements of these species comparable to the others, the total number of spores of each length has been calculated in the percentage of the total number of spores measured.

METHOD OF TABULATION.

For better comparison, the spore measurements have been tabulated by half microns, all the spores in each specimen coming within 0.2 of a micron of each unit or half being grouped together; e. g., all the spores having a length of 7.3, 7.4, 7.5, 7.6, and 7.7 microns are included under the heading 7.5. The tables thus show at a glance the number of spores of a given length per specimen. The widths have been tabulated in the same way.

For a better comparison of the shapes of the ascospores of *Endothia parasitica* and *E. fluens*, the relative ratios of length to width in each spore have been calculated, the width being considered unity. The ratios of length to width were then tabulated by tenths; that is, all the spores in each specimen having a ratio of length to

width from 1.76 to 1.85 microns are included under 1.8. The relative shapes of the spores in each specimen are thus clearly shown.

TABLE I.—Measurements of pycnospores and asci of *Endothia*.

PYCNOSPORE MEASUREMENTS.

Specimens.	Number per specimen having the given length or width.															Total.	
	Lengths (microns).												Widths (microns).				
	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	1	1.5	2	2.5		
Sphaeria gyrosa Schw., Herb. Mus., Paris.	2	3	6	11	4							9	15	2		26	
S. gyrosa Schw., Herb. Schwaeg.			5	9	3							5	11	1		17	
Endothia gyrosa on beech, Alcorn, Miss., No. 1796.			10	11	3							5	18	1		24	
E. singularis, No. 1939			4	6	4								5	9		14	
E. fluens, Sowerby				8	11	6							8	17		25	
E. fluens on chestnut, Fort Payne, Ala.			1	6	12	5	1						6	19		25	
E. fluens, Lugano, Switzerland.			1	3	5	2	1						8	4		12	
E. fluens mississippiensis, No. 1706A.			2	5	8	1							7	9		16	
E. longirostris.	2	3	4	4	1							6	8			14	
E. tropicalis.				2	5	6	3	3	2		4		3	19	3	25	
E. parasitica, No. 1696.			1	6	11	6	1						12	13		25	

LENGTHS OF ASCI (MICRONS).

Specimens.	No.	Number per specimen having the given length.								Total.
		25	30	35	40	45	50	55	60	
<i>Endothia fluens</i> on Castanea.	1702	2	8	11	1					22
Do.	1737		1	14	11					26
Do.	1741		5	6						11
Do.	1729		4	16	6					26
<i>E. fluens</i> on dead Castanea.	1715		7	16	3					26
<i>E. fluens</i> on Castanea, Stresa, Italy.	1656		6	16	1	1	1			25
<i>E. fluens</i> on Quercus.	1711	2	16	7						25
Do.	1927	2	10	12						24
<i>E. fluens mississippiensis</i> , Blue Mountain, Miss.	1806		5	14	3					22
<i>E. parasitica</i> on Castanea.	1710		1		1	2				4
Do.	1739			5	10	10	1			26
<i>E. parasitica</i> , China.	2151				2	14	4	4	3	27
<i>E. gyrosa</i> on Quercus.	1709	1	7							8
<i>E. gyrosa</i> on Liquidambar.		19	6							25
<i>E. singularis</i> , Palmer Lake, Colo.		4	15	5						24
<i>E. longirostris</i> , Porto Rico.		6	13	3	3					25
<i>E. longirostris</i> , French Guiana.		6	10	1						17
<i>E. tropicalis</i> .						6	5	3	2	16

WIDTHS OF ASCI (MICRONS).

Specimens.	Number per specimen having the given width.							Total.
	4	5	6	7	8	9	10	
<i>Endothia gyrosa</i> .			8	2				10
<i>E. singularis</i> .	1	8	2					11
<i>E. fluens</i> , Europe.			2	6	4			12
<i>E. fluens</i> , America.			1	6	4			11
<i>E. fluens mississippiensis</i> .			2	6	2			10
<i>E. longirostris</i> , Porto Rico.		2	7	2				11
<i>E. longirostris</i> , French Guiana.			3	3	3			9
<i>E. tropicalis</i> .				2	6	2		10
<i>E. parasitica</i> , China.				1	7	2		10
<i>E. parasitica</i> , America.					6	4		10

PYCNOSPORES.

The pycnospores of all the species are oblong elliptic to cylindric in shape and so small as to make accurate measurement very difficult. Slight but apparently constant differences in their size in certain groups of species may, however, be traced. These differences are clearly shown in Table I.

Endothia gyrosa, *E. singularis*, and *E. longirostris* have smaller pycnospores than the other species, the most frequent lengths being 3 and 3.5 μ . The pycnospores of *E. singularis* are slightly broader than those of *E. gyrosa* and *E. longirostris*, being 1.5 to 2 μ , as against 1 to 1.5 μ in the last two species.

Endothia fluens, *E. fluens mississippiensis*, and *E. parasitica* are even more closely similar in the size of their pycnospores than in that of their ascospores, the most frequent size being 4 by 2 μ . The pycnospores of *E. tropicalis* are much larger and more variable in size and shape than those of other species. They range from 3.5 to 7 μ in length and from 1.5 to 2.5 μ in width.

ASCI.

The writers have not attempted a study of the origin and early development of perithecia or asci in any of the species of *Endothia*. Work on this subject has been published by Anderson and Rankin (6), for *Endothia parasitica*, but the nuclear phenomena and origin and development of the ascogenous hyphæ are not yet entirely clear. The part termed a trichogyne by these authors seems more likely to be the initial stage in the development of the neck of the perithecium than the relic of an organ of fertilization.

The asci appear almost or quite sessile in most species, and though varying considerably in size and shape, as indicated in Table I, are usually oblong elliptic or subclavate, having a sort of inner membrane inclosing the ascospores and some thin granular matter extending to the apex of the ascus, where a slight thickening appears, as described and illustrated by Anderson for *Endothia parasitica*. A similar condition is found in various species of *Pyrenomycetes* and probably functions in some way in connection with the discharge of the ascospores. The asci are generally wider and slightly longer in *E. parasitica* than in *E. fluens* and other members of section 2. The asci of *E. gyrosa* are shorter than those of any other species. *E. tropicalis* has the longest asci. The asci of none of the species show a very wide range of variation, as Table I also indicates.

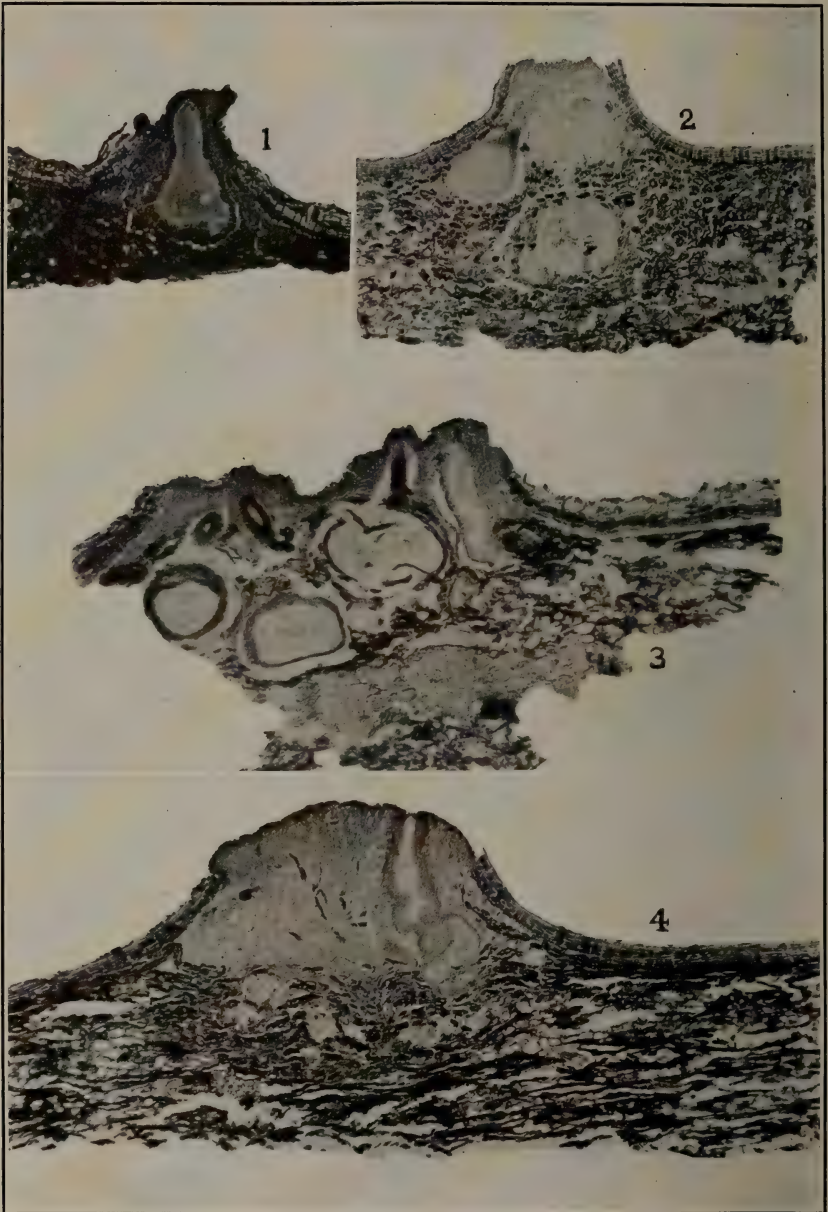
PARAPHYSES.

Most students of *Endothia* have reported paraphyses wanting in this genus. Anderson (1, p. 33, fig. 32) and Anderson and Rankin (6, p. 579, fig. 83) report paraphyses present and figure what they



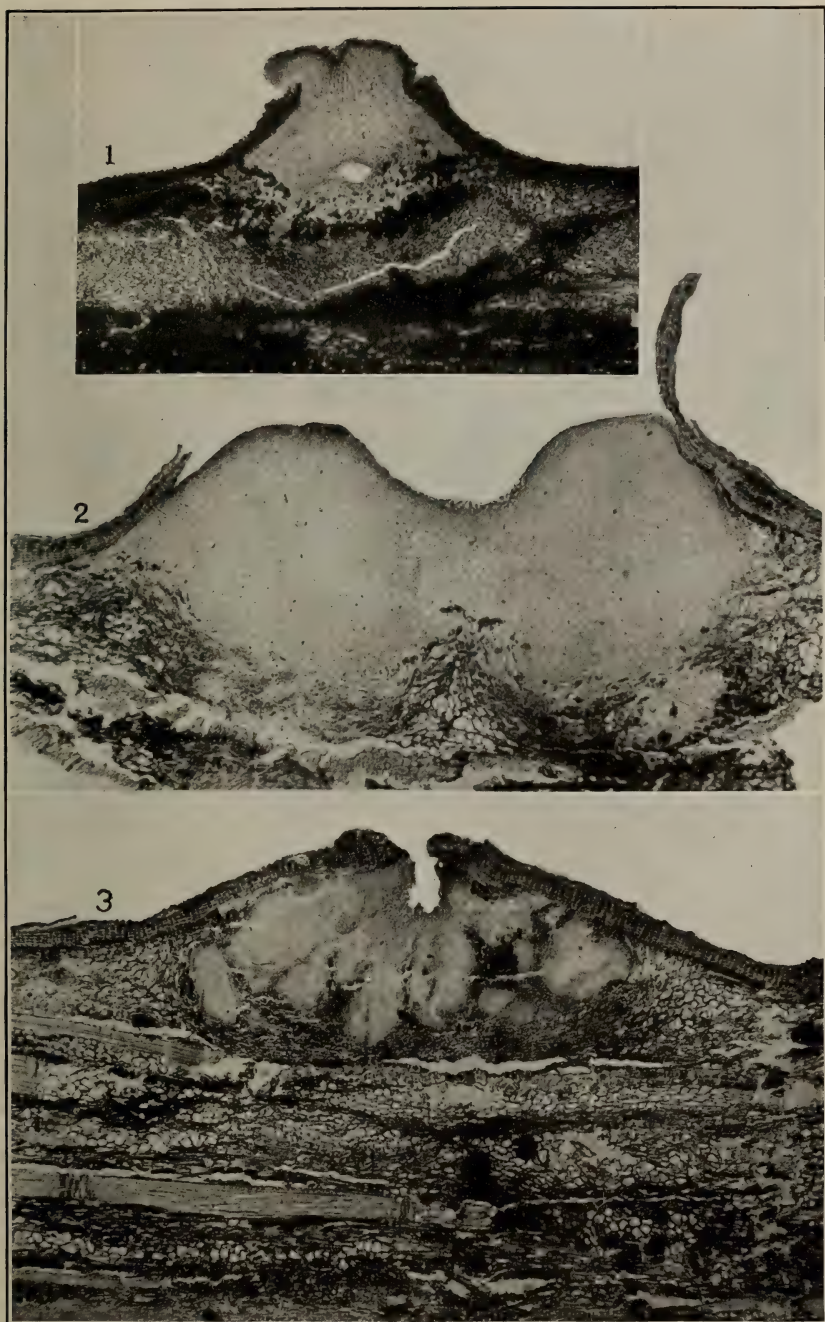
ENDOTHIA SINGULARIS. VERTICAL SECTION OF THE MAJOR PART OF A PYCNIDIAL STROMA. $\times 32$.

Paraffin section stained with Bismarck brown.



ENDOTHIA FLUENS. VERTICAL SECTIONS. $\times 49$.

FIG. 1.—SIMPLE PYCNIDIUM WITH VERY LITTLE STROMA, FROM ITALY. FIG. 2.—STROMA FROM ITALY, SHOWING A PERITHECIUM ABOVE A PYCNIDIUM. FIG. 3.—STROMA FROM AMERICA, SHOWING A MATURE PYCNIDIUM AND PERITHECIA SIDE BY SIDE. FIG. 4.—STROMA, SHOWING A SINGLE PYCNIDIUM AND FUNDAMENTS OF PERITHECIA BELOW.



ENDOTHIA PARASITICA. VERTICAL SECTIONS OF STROMATA. $\times 49$.

FIG. 1.—SHOWING A YOUNG, SIMPLE PYCNIDIAL CAVITY AT THE BASE. FIG. 2.—IN WHICH NEITHER PYCNIDIA NOR PERITHECIA HAVE BEGUN TO DEVELOP. FIG. 3.—WITH IRREGULAR CHAMBERED PYCNIDIA.

All the above are about the same age—four months after inoculation.



ENDOTHIA PARASITICA AND E. FLUENS. VERTICAL SECTIONS OF STROMATA. $\times 20$.

FIG. 1.—*E. PARASITICA*. SHOWING PERITHECIA ARRANGED IN SEVERAL IRREGULAR LAYERS. FIG. 2.—*E. PARASITICA*, SHOWING PERITHECIA ARRANGED IN A SINGLE LAYER. FIG. 3.—*E. FLUENS*, FROM ITALY, SHOWING PERITHECIA ARRANGED IN SEVERAL LAYERS.

regard as an early stage of their development. They describe them as branching frequently and very crooked, extending around the perithecium as well as upward. The writers have searched in all the species studied for evidence of the presence of paraphyses, but have never seen anything resembling paraphyses as they occur in closely related Pyrenomycetes. If they occur, they would seem to be of an unusual character and difficult to recognize or else are evanescent, disappearing before the asci are mature.

ASCOSPORES.

The ascospores furnish one of the most marked characters for the separation of the genus into sections (Plate XVII). In section 1 they are more or less cylindric and sometimes curved. In section 2 they are more or less elliptic, being broadest in *Endothia parasitica* and narrowest in *E. fluens* and *E. longirostris*. The greatest variation in size and shape of ascospores occurs in *E. fluens*, as indicated by the measurements given in Table II. Anderson (1), Clinton (18), and Heald (39) describe and figure the ascospores of *E. parasitica* as very obtuse and constricted at the septum. The writers have but rarely seen spores of this form. This may perhaps be due in part to different methods of treatment or to the age and condition of the material. Most of the ascospores studied by the writers have been mounted in the fluid medium described on page 30. Fresh specimens have also been studied in water mounts, but with the same general result. The writers are of the opinion, therefore, that the figures of the authors cited above do not represent the most common and characteristic form of ascospores of this species. (Compare Plate XVII, figs. 7 to 15.)

TABLE II.—*Measurements of ascospores of Endothia.*

Specimens.	No.	Number per specimen having the given length or width.																				Total.		
		Lengths (microns).										Widths (microns).												
		6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	1.5	2	2.5	3	3.5	4	4.5		5	
<i>Endothia gyrosa</i> on Liquidambar, Cyprus, Tenn.....	1797			1	15	13		22	11	7	5	4	1			57	42	2						
<i>E. singularis</i> on <i>Quercus utahensis</i> , Palmer Lake, Colo.....				3	10	9	23	27	11	11	2	2		1	6	77	15	1						
<i>Sphaeria radialis</i> , Fries herbarium.....		12	15	33	24	5	1	1										52	34	5				
<i>Endothia fluens</i> on <i>Castanea dentata</i> :																								
Taylorsville, N. C.....	1729	5	6	12	25	18	18	8	3	2		1					1	23	43	28	3			
Connellsville, Pa.....	1702	12	18	19	24	13	9	3	1									40	57	2				
Forest, Va.....	1741	3	6	12	27	8	22	16	3			1					1	34	47	15	1			
Monticello, Va.....	1737		2	10	16	19	21	16	9	4	1		1					1	25	65	8			
<i>E. fluens</i> : <i>Quercus cocinea</i> , On Blacksburg, Va.....	1927		7	25	27	6	5	1										7	40	24				
From dead <i>Castanea dentata</i> , Asheville, N. C.....	1715	2	15	18	19	19	12	8	1			1						25	62	8				
On stump of <i>Castanea vesca</i> , Stresa, Italy.....	1656			8	12	13	31	17	6	7	3	1	2	1				3	30	67	1			
On <i>Castanea vesca</i> , Como, Italy.....	1637			10	18	18	24	16	8	2	1	1						42	47	9				
Do.....	1655	1	1	12	26	19	15	18	5	2	1							37	51	12				
Total.....		23	55	126	194	133	157	103	36	17	6	5	3	1			2	212	402	230	13			
Per cent.....		2.6	6.4	14.6	22.6	15.5	18.3	11.9	4.9	1.9	0.7	0.6	0.3	0.1		0.2	24.7	46.7	26.7	1.4				
<i>E. pseudoradicis</i>		4	13	28	27	16	11	1										29	57	14				
<i>E. fluens mississippiensis</i> : On <i>Castanea dentata</i> , Blue Mountain, Miss.....	1782		3	9	11	10	8	5	1	1		1						7	36	6				
Do.....	1806	4	2	18	13	5	8	1										20	27	4				
Total.....		4	5	27	24	15	16	6	1	1		1						27	63	10				
<i>E. longirostris</i> : Porto Rico.....		6	10	28	31	14	10	1										50	47	3				
French Guiana.....		7	14	24	36	11	6											28	60	10				

Endothia tropicalis:	3	9	22	35	20	9	2	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	43	28	50	4
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¹ Specimens of American material sent by Pantanelli, of Rome, Italy.

PHYSIOLOGY.

CULTURAL STUDIES.¹

During the past three years the writers have had under observation more than 4,000 cultures of the several species of *Endothia* on more than a dozen artificial media, as well as on sterilized twigs of many kinds. Throughout this work the writers have been impressed with the uniformity of the behavior of the organism in culture and the certainty with which the various species could be distinguished on any of the media used.

Cultures of *Endothia parasitica*, for instance, from specimens sent from China or British Columbia were absolutely indistinguishable from cultures made on the same medium from local material. Transfers made from stock cultures which had been kept on artificial media for two years were identical with transfers from freshly collected material. The same remarkable constancy held for the other species. Cultures from material collected in different localities or from different hosts were identical, not only in appearance but, so far as the writers were able to determine, in temperature and moisture relations also. As previously noted, this is in marked contrast to the senior writer's experience with the species of *Glomerella* and it is believed differs from the experience of many investigators of fungi.

No less striking is the certainty with which the several species may be distinguished on any medium tried. *Endothia parasitica*, *E. tropicalis*, and *E. fluens* and its variety *mississippiensis* are very closely related morphologically. Moreover all except *E. parasitica* have, as near as could be determined, much the same relation to their hosts. Yet each species has distinctly and readily recognized characters on culture media.

It should not be imagined, however, that the differences are recognizable at once as clearly distinctive characters. The differences at first glance might readily be considered fluctuating variations. But the fact that the characters remain constant through hundreds of generations and have never varied toward one another makes them worthy of recognition as specific characters.

In a previous paper (77) the writers described their results with cultures of *Endothia parasitica*, *E. fluens*, *E. fluens mississippiensis*, and *E. gyrosa* on a number of culture media. At that time the work of other investigators was reviewed and the methods of preparing the various culture media and making the cultures described. Since the publication of that paper, however, cultures of two more species, *E. tropicalis* and *E. singularis*, have been secured and about 2,000 additional cultures of the various species made. In addition to the culture media mentioned in the previous paper (77, p. 10), the writers

¹ The cultures described were all grown at ordinary laboratory temperatures in the winter, about 20° to 24° C.

have grown the organisms on sterile twigs of many species and on liquid media.

As stated above, the various species of *Endothia* are distinguishable on any medium tested. White corn meal in flasks has, however, been most used by the writers in identification work and for keeping stock cultures. All the species grow readily on this medium and may be determined with certainty within 10 days under ordinary conditions of growth. In addition, the medium is cheap, easily prepared, and does not dry out so quickly as agar media in tubes, so cultures may be kept alive much longer without transfers. Almost equally good for purposes of identification are rice and oatmeal in flasks, corn-meal agar, and potato agar.

The distinguishing characteristics of the various species in culture have been described rather fully in the previous publication and may be briefly summarized, as follows:

CULTURES ON CORN-MEAL AGAR (UNSLANTED TUBES).

Corn-meal agar proved the best agar medium for the production of pycnospores and showed constant differences in the cultural characters of the various species. The most characteristic differences appeared in cultures from six to eight weeks old on unslanted tubes. (See Pl. XXI, figs. 2 to 7.)

Endothia gyrosa at this age showed a rather abundant, felty white mycelium, flecked with capucine buff, but there were no pycnidia. In older cultures small pycnospore threads were sometimes produced. Usually before the cultures were 10 days old the medium was changed to a delicate lavender just below the mycelium, and below this to a light olive green. A few days later the lavender disappeared and the green deepened to olive green.

Endothia singularis grew more slowly than any other species. Within three weeks, however, the mycelium covered the entire surface. It was smoother than *E. gyrosa* and nearly white, with raw umber spots where the mycelium touched the glass. The medium was changed to a light hellebore green one-half inch below the top.

Endothia fluens, as pointed out in the previous paper, produced an abundant deep-chrome mycelium, with usually one or two rather small pycnidial pustules.

Endothia fluens mississippiensis produced a scant surface growth of mycelium, between cadmium yellow and raw sienna in color. The upper one-half centimeter of the agar became reddish orange. The pycnidial pustules were more numerous than those of *E. fluens*, but smaller and more scattered than those of *E. parasitica*.

Endothia longirostris at the end of six weeks had a scant, webby, orange, aerial mycelium growing against the glass. Mycelium on the surface of the medium was very scant, orange to cadmium yellow in color, with scattered tiny xanthine orange to orange spore masses. The color of the agar changed to medal bronze just beneath the mycelium, shading into orange citrine below.

Endothia tropicalis at the end of six weeks showed a thinly felted mycelium, white to capucine orange, with numerous small, scattered pycnidial pustules. The ring of mycelium against the glass was light orange yellow, as contrasted with white in *E. parasitica*.

Endothia parasitica gave a scanty white growth of surface mycelium, with several prominent pycnidial pustules clustered near the center and of a slightly darker shade than the "raw sienna" of Ridgway.¹

CULTURES ON POTATO AGAR (SLANTED TUBES).

Potato agar was used by the Andersons (3) to distinguish *Endothia parasitica* from *E. fluens*. The writers have used it extensively and found it a very useful medium for distinguishing the species. As stated in the previous paper (77, p. 11), however, unless this medium was very carefully prepared it varied greatly in acidity and probably in other respects, with resultant variations in the behavior of the organisms. Spore production was not so abundant on this medium as on many others. The preparation of this and other media is described in the paper cited.

Endothia gyrosa.—This species developed rather slowly, producing a fairly abundant aerial growth, which was felty rather than fluffy. The color was white, flecked with capucine buff, and no spore masses were produced.

Endothia singularis.—This species grew even more slowly than *E. gyrosa*. On cultures made from conidia, growth was hardly perceptible at the end of three days. Mycelial cultures at the end of one week showed less growth than *E. gyrosa*, but did not differ greatly from it in either color or texture. At the end of one month the mycelium was slightly more fluffy and decidedly less in amount than that of *E. gyrosa*. Most of the surface was a very light buff color, with sometimes a few spots of capucine orange to English red.

Endothia fluens.—Pycnospore streak cultures of this species varied somewhat as to the amount and time of appearance of color, probably due to the variations in the acidity of the medium referred to above. Many tubes showed an orange color in one week, while others produced no orange whatever. In no case did cultures of *E. fluens* produce the "brassy" metallic surface appearance so characteristic of *E. parasitica*. Pycnidia were few and more scattered than in *E. parasitica* and did not begin to appear until the third or fourth week. A slight amount of warbler-green color sometimes appeared in the medium at this age, but never so conspicuously as in *E. parasitica*.

Endothia fluens mississippiensis.—This produced a less fluffy aerial mycelium along the spore streak than *E. parasitica*. After five or six days the fungus showed an orange color by transmitted light, and was indistinguishable in this respect from *E. parasitica*. The character of the surface was somewhat different, however, and by reflected light appeared xanthine orange. When two weeks old this form differed still more markedly from *E. parasitica* in color, being grenadine red by transmitted light and showing no spore masses.

E. longirostris.—At the end of one week this produced a white, fluffy growth scattered in small patches over the surface of the medium. This later became rather close in texture, especially near the base of the agar slant. No spores were produced on this medium.

Endothia tropicalis.—At the end of one week this showed less growth than *E. fluens*, covering about a third of the surface of the medium, while the other covered nearly the entire surface. The mycelium was closely matted and a very pale buff (paler than any in Ridgway). At the end of one month

¹ In the descriptions of cultures comparisons were necessarily made with cultures in flasks or tubes. This of course made comparison more difficult and somewhat less accurate than if the material had been removed from the container.

E. tropicalis covered the entire surface with a thin layer of surface mycelium, considerably darker in color than when one week old.

Endothia parasitica.—At the end of three or four days at room temperature this showed a short, fluffy, white, aerial growth along the streak. The surface of the mycelium was orange by transmitted light, while by reflected light it was between raw sienna and antique brown at the sides. Within six days the mycelium, especially at the base of the agar slant, took on a peculiar metallic "brassy" appearance, due apparently in part to the character of the mycelium and in part to the minute water drops scattered over the surface. This portion of the culture was light orange yellow by reflected light and orange by transmitted light. This metallic appearance has been found to be the most constant and reliable distinguishing character of *E. parasitica* on potato agar. In 12 to 14 days small pycnidial pustules appeared in the upper portion of the tubes, and the agar just below the mycelium became warbler-green, changing later to olive green.

CULTURES ON CORN MEAL (IN 100 C. C. ERLLENMEYER FLASKS).

Endothia gyrosa.—Mycelial cultures one week old showed a growth of rather compact mycelium covering nearly one-half the surface of the medium. The mycelium was ochraceous buff near the point of inoculation, shading into white at the margin. There was no discoloration of the medium and no spore masses were seen.

Cultures of the same kind one month old showed an abundant, rather thick growth, having the surface mostly covered with somewhat irregular tubercular masses, suggesting immature pycnidial stromata similar to those found in *E. radicalis*, but smaller and producing no spores. The surface of the culture was capucine buff, that of the tubercles honey yellow to Isabella. The dark color was apparently due in part to numerous superficial water drops. A portion of the medium was changed to perilla purple.

Endothia singularis.—Mycelial cultures one week old covered only one-third of the surface. The growth was mostly white and fluffy, with ochraceous buff near the center.

At the end of one month the growth had entirely covered the surface. The mycelium varied in color from cadmium orange to capucine buff, the color being distributed over the surface in patches. The corn meal was changed to perilla purple near the center. No spores were produced.

E. singularis was readily distinguishable from *E. gyrosa*, which it resembled more closely in culture than any of the other species, by the rate of growth and the color and nature of the surface of the mycelium. *E. singularis* grew more slowly than *E. gyrosa*, was rather brighter in color (cadmium orange), and the surface of the mycelium was decidedly more even, lacking the tubercular masses characteristic of *E. gyrosa*.

Endothia fluens.—Cultures at the age of one week showed a growth of loose, fluffy mycelium covering one-half of the surface of the medium. The mycelium was deep chrome to light orange yellow at the point of inoculation, passing through perilla purple and light pinkish lilac and fading into white at the margin. Occasionally the medium was changed to perilla purple near the center. No spores were present.

Cultures one month old showed a compact growth, with a nearly smooth surface. The color ranged from light cadmium to empire yellow. The whole mass of the medium was perilla purple. Spore masses were rarely present at this stage, but shortly afterwards a few large erumpent stromata were formed, which extruded spores in thick masses.

Endothia fluens mississippiensis.—Cultures one week old showed an orange-chrome growth a little more than half covering the surface of the medium. The superficial growth was very similar to that of *E. parasitica*. There was no discoloration of the medium and no spore masses were found.

The same organism one month old produced a growth with a compact, rather uniform surface, the superficial portion having a coarse, matted, webby appearance, which was most noticeable about the margin. The color of the mycelium was cadmium orange to xanthine orange, while that of the medium was unchanged. Spore masses were much more numerous than in *E. fluens*, but smaller and less numerous though very similar to those of *E. parasitica*.

E. longirostris.—Cultures one week old covered about one-third of the surface of the medium. The mycelium was short, fluffy, white, with only a tiny spot of cadmium orange near the point of inoculation. At the end of six weeks the entire surface was covered with a compact growth rather uniform in texture, cadmium orange to xanthine orange in color. The surface was irregularly ridged, giving it a wrinkled appearance, with tiny mars orange spore masses irregularly scattered over the surface. This species closely resembles *E. fluens mississippiensis* on this medium, being distinguished from that variety by the smaller and much less numerous spore masses. The medium is changed to amber brown just below the mycelium, shading into mars yellow in the lower portions.

Endothia tropicalis.—At the end of one week this showed less growth than either *E. parasitica* or *E. fluens*, covering about a third of the surface. The mycelium was matted close to the surface and was a very pale buff (paler than any of the buffs shown in Ridgway). No pycnidia were present.

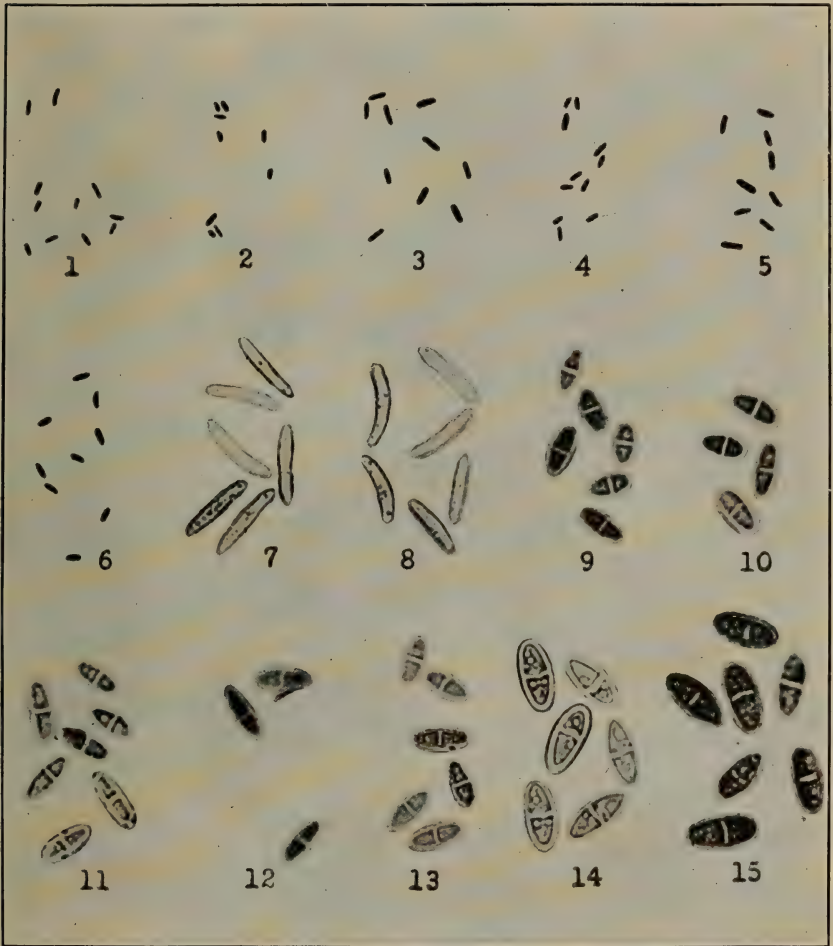
At the end of one month's growth the surface was entirely covered with a closely felted mycelium and small, numerous, thickly scattered spore masses, more closely resembling those of *Endothia parasitica* than any other species. The mycelium was orange buff to apricot orange, and orange chrome against the glass. The color of the medium was unchanged.

Endothia parasitica.—In cultures one week old the growth on corn meal covered about one-half of the surface of the medium. The outer margin was pure white, the remainder buff yellow below, with a superficial white growth above. A few small pustules with spore masses occurred near the point of inoculation. The medium was uncolored.

Cultures one month old showed a compact growth, nearly smooth on the surface. The superficial mycelium was pale orange yellow. The pale yellow-ocher spore masses were minute, very numerous, and nearly covered the surface. The medium was slightly greenish about the sides of the flask just beneath the mycelium.

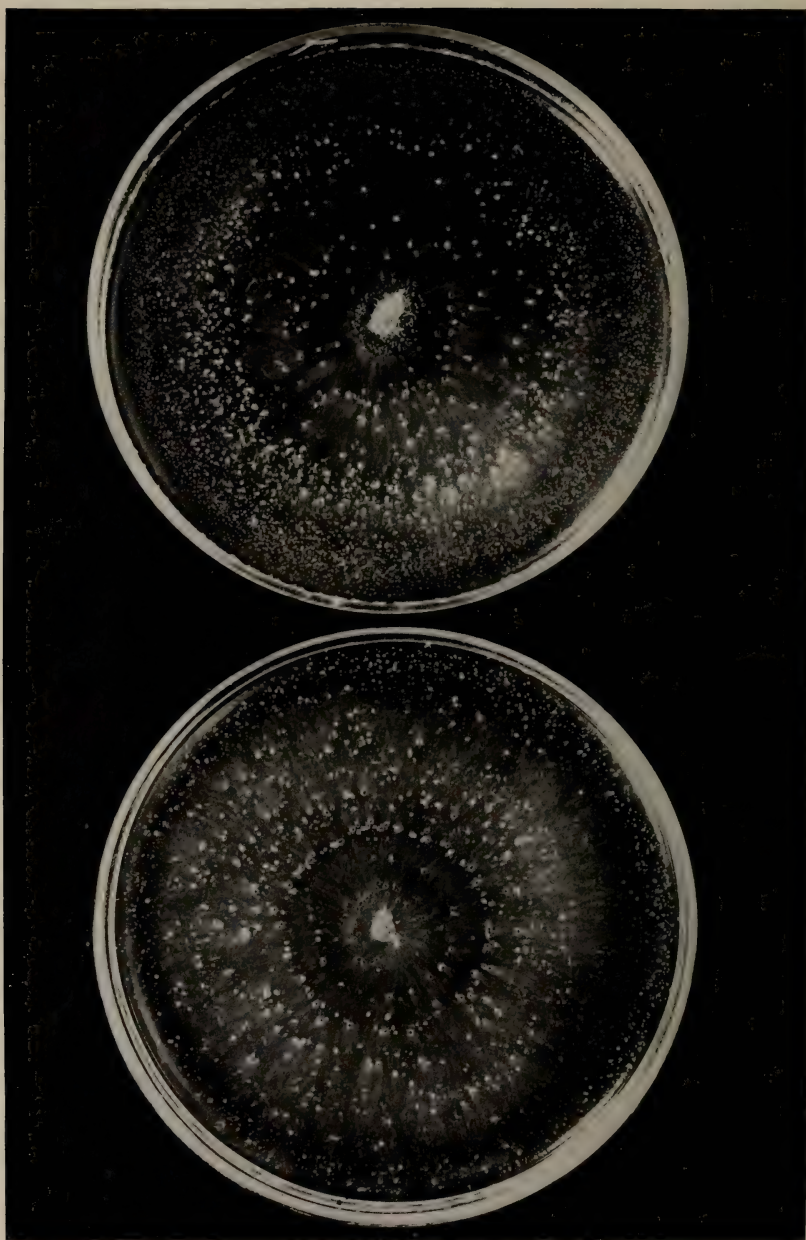
DISTINGUISHING CHARACTERS OF THE VARIOUS SPECIES ON CORN MEAL IN FLASKS.

The color reactions of the various species on corn meal are very striking. *Endothia fluens* (Pl. XXI, fig. 1b), as noted above, changes the whole mass of the medium to perilla purple in less than a month. *E. gyrosa* and *E. singularis* also produce this color change, but somewhat more slowly. *E. fluens mississippiensis*, *E. tropicalis*, and *E. parasitica*, on the other hand, in hundreds of cultures have wholly failed to produce any purple color. This furnishes an easy and reliable method of distinguishing *E. parasitica* from *E. fluens*

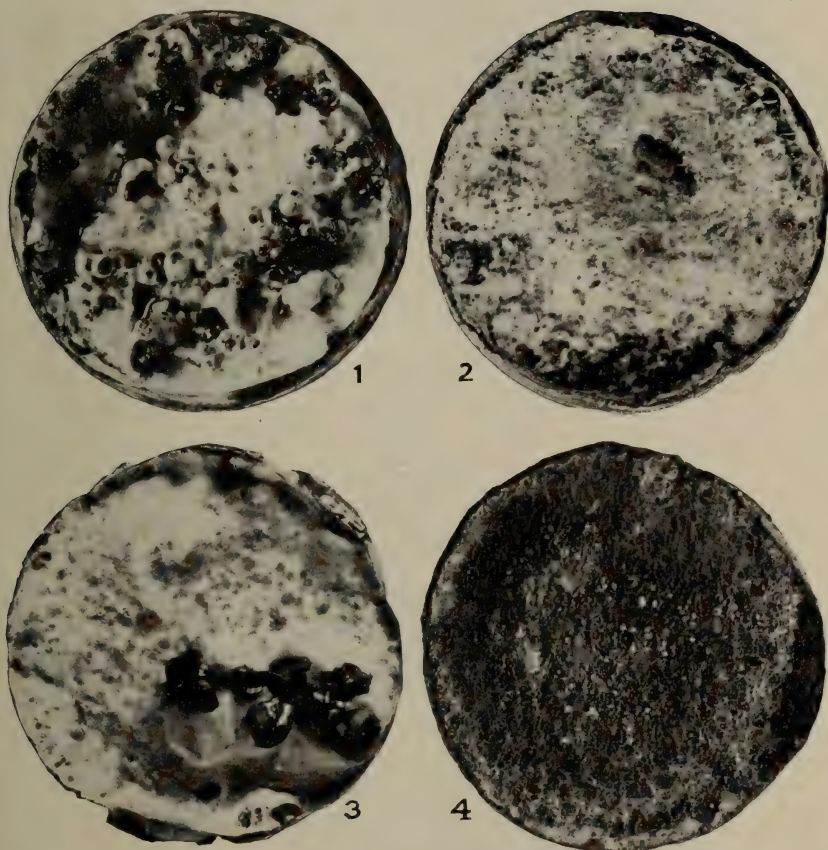


PHOTOMICROGRAPHS OF PYCNOSPORES AND ASCOSPORES OF
ENDOTHIA.

FIGS. 1 TO 6.—PYCNOSPORES: 1, *ENDOTHIA GYROSA*; 2, *E. SINGULARIS*; 3, *E. FLUENS*; 4, *E. LONGIROSTRIS*; 5, *E. PARASITICA* (AMERICAN); 6, *E. PARASITICA* (CHINESE).
FIGS. 7 TO 15.—ASCOSPORES: 7, *E. GYROSA*; 8, *E. SINGULARIS*; 9, *SPHAERIA RADICALIS*, FROM SCHWEINITZ'S SPECIMEN IN FRIES'S HERBARIUM; 10, *ENDOTHIA PSEUDORADICALIS*; 11, *E. FLUENS*; 12, *E. FLUENS MISSISSIPPIENSIS*; 13, *E. LONGIROSTRIS*; 14, *E. TROPICALIS*; 15, *E. PARASITICA*.

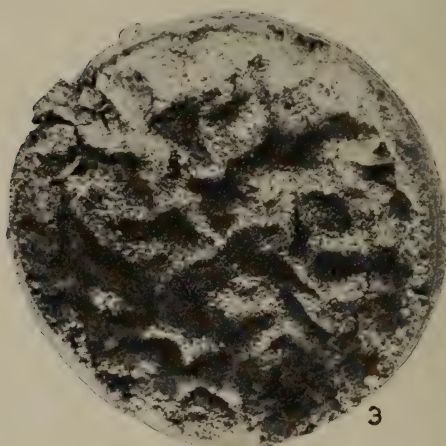
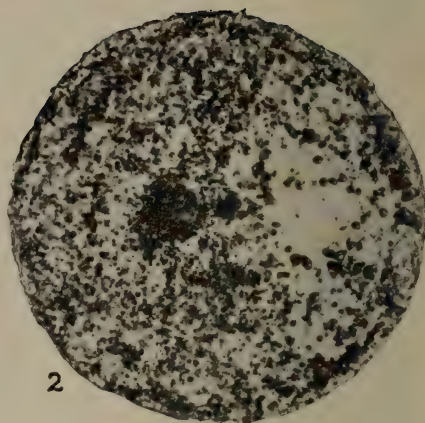
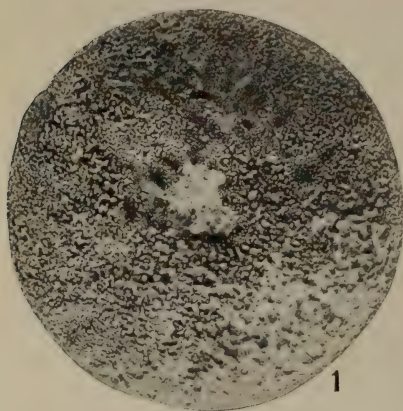


ENDOTHIA PARASITICA ON PLATE CULTURES OF CORN-MEAL AGAR 4 WEEKS OLD. THE UPPER PLATE WAS KEPT IN TOTAL DARKNESS; THE LOWER PLATE IN THE DIRECT LIGHT OF A NORTH WINDOW.



ENDOTHIA SPECIES ON WHITE CORN MEAL (10 GRAMS OF CORN MEAL TO 20 C. C. OF WATER). CULTURES 2 MONTHS OLD.

FIG. 1.—*ENDOTHIA GYROSA*; FIG. 2.—*E. SINGULARIS*; FIG. 3.—*E. FLUENS*; FIG. 4.—*E. FLUENS MISSISSIPPIENSIS*.



ENDOTHIA SPECIES ON WHITE CORN MEAL (10 GRAMS OF CORN MEAL TO 20 C. C. OF WATER). CULTURES 2 MONTHS OLD.

FIG. 1.—ENDOTHIA TROPICALIS; FIG. 2.—E. PARASITICA; FIG. 3.—E. LONGIROSTRIS.



MS. Hatley

CULTURES OF ENDOTHIA SPECIES

FIG. 1.—*a*, Corn meal after 1 month's growth of *Endothia parasitica*; *b*, corn meal after 1 month's growth of *E. fluens*.

Typical cultures on upright tubes of corn-meal agar 6 weeks old. FIG. 2.—*E. gyrosa*. FIG. 3.—*E. singularis*. FIG. 4.—*E. fluens*. FIG. 5.—*E. fluens mississippiensis*. FIG. 6.—*E. tropicalis*. FIG. 7.—*E. parasitica*.

(Pl. XXI, fig. 1) in field work when fructifications of the species are wanting or doubtful.

Aside from the differences in color, the most conspicuous and important characteristic of these fungi in corn-meal cultures is found in the fructification. Clinton (18, pl. 26) has already mentioned and illustrated similar differences in cultures of these organisms on agar in Petri dishes. In *Endothia parasitica* the pycnidia and spore masses are small, numerous, thickly scattered, and embedded in the mycelium. *E. fluens*, on the other hand, forms few, large, erumpent stromata, with spores extruding in thick, elongated masses. *E. tropicalis* closely resembles *E. parasitica* in number, size, and arrangement of pycnidia and spore masses, but differs in color of mycelium. *E. fluens mississippiensis* appears somewhat intermediate between *E. parasitica* and *E. fluens* in regard to the character and abundance of the pycnidia and in color of the growth. These peculiarities have been very uniform and constant in all the cultures on this medium and if they could be coordinated with regular morphological differences in nature would justify the separation of this form as a species. (See Pls. XIX and XX.)

CULTURES ON LIQUID MEDIA (IN 100 C. C. FLASKS).

Some difficulty was experienced at first in growing the species of *Endothia* satisfactorily on a liquid medium. Abundant growth was obtained on a medium suggested by Dr. Mel. T. Cook. This is a modification of the liquid medium No. II as given by him (19).

Cook's liquid medium, No. II, is prepared as follows:

Into 500 c. c. of distilled water put 15 grams of glucose and 20 grams of peptone steamed at 100° C. for three-fourths hour; into another 500 c. c. of distilled water put 0.25 gram of dipotassium phosphate and 0.25 gram of magnesium sulphate, steamed for 20 minutes; filter both 500 c. c. into same receptacle, steam 10 minutes, put into flasks, about 30 c. c. in each flask, and autoclave.

All species grew readily on this medium, *Endothia parasitica* even producing pycnospores. At the end of one month's growth the several species were readily distinguished on this medium and may be briefly described, as follows:

Endothia gyrosa.—Growth scanty; did not form a continuous mat, but remained in small bunches, giving an almost flocculent appearance. The mycelium appeared white when removed from the culture solution, but the solution itself was honey yellow.

Endothia singularis.—Growth even less abundant than *E. gyrosa*; formed small brown knots against the glass. Mycelium buff, and the medium was changed to honey yellow.

Endothia fluens.—Growth somewhat more abundant and less closely matted than *E. parasitica*, entirely submerged; mycelium white; liquid unchanged in color.

Endothia fluens mississippiensis.—Growth slightly less abundant than in *E. parasitica*; submerged except at the very edges; much lighter in color, being reddish brown.

Endothia tropicalis.—This differed markedly from either *E. parasitica* or *E. fluens*. The mycelium formed a thin felt over the surface, white to salmon orange in color, with no change in the medium.

Endothia parasitica.—Mycelial growth very abundant, closely matted, chiefly submerged, but slightly arborescent in one or two small areas, which remained above the surface. Color, dark greenish brown.

CULTURES ON STERILIZED TWIGS (IN TUBES).

Early in this work it was noted that all the species of *Endothia* grew readily on sterilized chestnut twigs in test tubes. Later, tests were made with twigs from a number of common, woody plants. Twigs of *Acer saccharum*, *Alnus rugosa*, *Betula papyrifera* and *B. lenta*, *Carpinus caroliniana*, *Cornus florida*, *Fagus grandifolia*, *Fraxinus americana*, *Ostrya virginiana*, *Populus grandidentata*, *Prunus serotina*, *Rhus glabra*, *Tilia americana*, and *Tsuga canadensis* were collected in New York State early in June, placed in test tubes with a few cubic centimeters of distilled water and sterilized in an autoclave. All the species of *Endothia* were tested, and all grew on every species of twig except *Tsuga*. The difficulty of completely describing this series may readily be seen from the fact that each species of *Endothia* had a different appearance on every kind of wood.

In general it may be stated that *Endothia gyrosa* and *E. singularis* grew more slowly than the other species and produced no spores, while all the other species produced spores on most hosts. The mycelium of *E. parasitica* was usually white, especially on the bark. *E. gyrosa* and *E. singularis* produced various shades of buff, while *E. fluens*, *E. fluens mississippiensis*, and *E. tropicalis* developed a much more brightly colored mycelium, usually showing yellow or orange shades.

MOISTURE RELATIONS.

In an earlier paper (77, p. 7) the writers reported tests with *Endothia fluens* and *E. parasitica* on media containing various percentages of water. It was observed that pycnospore production began earliest and was most abundant on the media containing the least moisture.

Aside from this the writers have thus far been unable to make definite tests as to the moisture relations of these fungi. However, incidental observations in connection with the light tests (p. 43) and temperature tests (p. 45), as well as results of field experiments, particularly those at Woodstock, N. Y., make it apparent that the amount of available moisture is a very important factor in the fructification of the fungus.

LIGHT RELATIONS.

The relation of light to pycnospore production in *Endothia parasitica* was first discussed by Anderson (1, p. 20). He says—

When plate cultures are grown in total darkness on chestnut-bark agar, no pycnidia are developed, while on plates made at the same time and grown in the light, the usual rings of pycnidia appear (fig. 57). Experiments were also tried in which the plate was left in darkness until about half covered with mycelium and then brought into the light. Circles of pycnidia were developed, beginning with the ring which marked the outermost limit of the colony when removed from the dark chamber. The concentric rings which always appear on agar cultures are due to the alternation of night and day.

Later, in a bulletin by Anderson and Rankin (6, p. 592), the same results are attributed to D. C. Babcock.

Up to the time the above-mentioned work was published the writers had grown about 3,000 cultures of the several species of *Endothia* on various media in flasks and tubes. Practically all of these cultures had been kept in dark cases and *Endothia parasitica* had produced pycnidia abundantly on most of the media used. It seemed desirable, therefore, to determine whether wholly different light relations existed when the fungus was grown on plates. The following series of tests was accordingly made, using *E. parasitica* only.

LIGHT TESTS OF CULTURES ON PLATES.

In experimenting with plate cultures in order to check up the results reported by Anderson and Rankin (6, p. 592) it was noted that there was great variation in the rate at which the cultures dried out. There was considerable variation in this respect in different plates kept side by side, apparently due to differences in the Petri dishes, and a marked difference between cultures kept in light and those kept in darkness. Since a causal relation between lack of moisture and abundant spore production had already been shown, it seemed probable that this might influence the results of the light tests in plate cultures. In fact, in a few cases the cultures kept in the light did produce spores earlier than those kept in darkness. Accordingly, in order to eliminate at least in part this fact which seemed to obscure the possible effect of light, a method was sought of equalizing the loss of moisture. In the following series half the plates were placed under a plain bell jar and the other half under a bell jar of equal size but darkened by being covered inside and out with heavy black paper, such as is used to wrap photographic plates. The two bell jars were then set side by side in front of a north window. By this means the conditions were made much more uniform as to temperature and moisture. There was still a slight difference in the rate of drying and undoubtedly at times a difference

in the temperature of the light and dark plates, but probably not sufficient to interfere seriously with the experiments.

Series 1. On corn-meal agar plates under bell jars.—In nine days there was no distinguishable difference between the plates in light and darkness, a few spore masses occurring near the middle of each.

In 18 days most of the light plates showed a central ring of spore masses and a zone of scattered spore masses near the edge. The dark plates showed a few small spore masses near the center, and scattered about the outer portion were the small masses of mycelium which usually constitute the early stages of pycnidial formation.

In 30 days the number of spore masses had increased somewhat in both sets of plates, but more in the darkened plates, so that the number of spore masses was about equal in all the plates. The two sets of plates were fairly uniform as to the arrangement of the spore masses. Plate XVIII shows a typical example.

Series 2. On chestnut-twigg agar plates under bell jars.—After nine days the cultures in light and darkness were alike. No spores had yet appeared in either set.

In 30 days there were a few spore masses on nearly all of the plates, there being no difference between those in light and those in darkness either in number or distribution.

Series 3. On corn-meal agar and chestnut-twigg agar under bell jars.—In this test the plates were piled alternately, first a corn-meal and then a chestnut-twigg agar plate, so that the two media would be under conditions as nearly identical as possible. The plates were inoculated as before and left untouched for 18 days and after that were examined daily. After 18 days all the corn-meal plates showed spore masses in practically equal numbers, while the chestnut-twigg agar plates showed no spore masses whatever. There was no apparent difference in the growth on either medium between the plates in light and those in darkness.

At the end of 25 days the cultures on chestnut-twigg agar plates showed numerous small masses of mycelium, indicating the formation of pycnidia. No difference was perceptible between the dark and light plates.

In 28 days, from 100 to 150 of these pycnidia in each plate were extruding spore masses. The light plates showed in general a larger mass of spores than the dark plates, but this was not marked, certainly no greater than was accounted for by the unavoidable difference in radiation and the consequent difference in moisture. This difference in the moisture of the medium was clearly shown each morning by the greater amount of moisture condensed on the covers of the darkened Petri dishes.

At this time (after 28 days) four corn-meal agar plates which had been wrapped in four layers of heavy black photographic paper and

placed on a window sill were opened and examined. In spite of the cold weather prevailing during this test and the consequent low temperature of the room at night, these plates contained an average of nearly 200 well-developed spore masses.

At the end of 35 days the chestnut-twigg agar plates which had been kept in the light showed an average of 160 spore masses, while those kept in darkness showed an average of 130 spore pustules, a comparatively small difference in favor of the light plates. There was, however, a wide difference between the various plates in each series, and it was impossible in most cases to distinguish cultures grown in the light from those grown in darkness either by the number, size, or arrangement of the pycnidia and spore masses.

From these experiments it is evident that pycnidia are produced abundantly in total darkness on chestnut-twigg agar as well as on other favorable media. There is no perceptible difference in the amount of spore production or in the arrangement of pycnidia between cultures kept in total darkness and those kept in the light during the day if the temperature and evaporation remain the same in both. Continued observation of numerous cultures grown both in daylight and in darkness has convinced the writers that light has no perceptible effect on mycelial growth either in amount, nature, or color production. It seems evident, therefore, that light is a negligible factor in the growth and fructification of these fungi.

TEMPERATURE RELATIONS.

In an earlier paper (77, p. 9) the writers published the results of three series of tests made to determine the temperature relations of three species of *Endothia*. Since the publication of that paper cultures of other species and additional material of some of the species from widely separated localities have been secured. Four series of temperature tests including this new material were made on solid media.

TESTS ON SOLID MEDIA.

In these tests cultures of *Endothia gyrosa*, *E. singularis*, *E. fluens*, *E. fluens mississippiensis*, and *E. parasitica* were tried on corn-meal agar in slanted tubes, oatmeal in flasks, and potato agar in slanted tubes. The cultures tested were from specimens chosen from the extremes of the known ranges of the fungi and from their different hosts. No difference could be detected in the various cultures of the same species, even in those from widely separated localities and from different hosts. Cultures appeared to have the same temperature relations whether made from spores or mycelium. The results may be briefly summarized as follows:

At 41° and 39° C. there was no growth in any species. Cultures removed from the incubator at the end of 11 days and kept at room temperature showed no growth.

At 35° C., *Endothia gyrosa*, *E. singularis*, and *E. parasitica* showed a slight development within 2 days, but at the end of 11 days it was still slight and abnormal in appearance. *E. fluens* and *E. fluens mississippiensis* showed no growth at this temperature.

At 31° C., *Endothia gyrosa*, *E. singularis*, and *E. parasitica* appeared about the same as at room temperature for the first four days. At the end of six days these species showed somewhat less growth than at room temperature, while at the end of two weeks the growth was less in extent and markedly less freshly colored than that at room temperature. *E. fluens* and *E. fluens mississippiensis* showed somewhat less growth than at room temperature even in 4 days, and markedly less at the end of 2 weeks.

At room temperature (which at this time varied from 20° to 24° C.) the growth was much as described in the previous paper. Within 11 days growth was practically complete and in 14 days there was abundant spore production in *Endothia parasitica*.

At 18° and 16° C., all species showed considerably less growth than at room temperature, but there seems to be little difference in the comparative growth of the various species at these temperatures. At 13° the growth was decidedly less than at 16° C. but was fairly normal in appearance in all the species except that *Endothia fluens mississippiensis* failed to produce the characteristic color at this temperature.

At 9° C. there was a very slight growth in all species.

At 7°, 5°, and 2° C. there was no growth whatever. Cultures removed to room temperature at the end of 11 days developed normally and at about the same rate as in newly made cultures.

These additional tests seemed to confirm the results already published (77, p. 27); that is, growth was best in all species at ordinary room temperature, about 20° to 24° C. The minimum temperature for all was about 9°, and all failed to grow at 7° C. The maximum temperature for *Endothia gyrosa*, *E. singularis*, and *E. parasitica* appeared to be about 35°, while the maximum for *E. fluens* and its variety *E. fluens mississippiensis* was apparently about 32° C. At all the temperatures tried *E. singularis* grew much more slowly than any of the other species.

It was noted that cultures kept at 7°, 5°, and 2° C. showed no growth, but when removed to room temperature developed normally, while cultures kept at 41° and 39° C. failed to grow when removed to room temperature. This seemed to indicate that the fungi are more susceptible to heat than to cold, and such is perhaps the case. There was, however, the additional factor of moisture involved, for while the agar of the cultures kept at 7° and lower was in apparently the same condition at the end of 11 days as when first inoculated, the agar of the cultures kept at 41° to 39° C. was considerably dried. This raised the question as to whether the drying out of the agar had not affected the growth of the fungi in those cultures kept above room temperature as much as the higher temperatures themselves.

The same idea was suggested by the fact that several of the species grew for a few days at 31° C. as well as they did at room temperature, and then fell behind. It seemed possible that this falling off in the

rate of growth might be due, at least partly, to more rapid drying of the agar at 31° C., or possibly to the more rapid development of some toxin, as was suggested by Balls (7) to explain a similar observation on the "soreshin" fungus. These observations threw doubt upon the accuracy of the writers' previous conclusions, and made it seem possible that the optimum temperature of the species of *Endothia* might be well above room temperature. This could only be determined accurately by some method which would control temperature without altering the supply of moisture. Some months after the above tests were concluded it was discovered that the various species of *Endothia* would grow readily on several liquid media. Consequently, several series of tests on liquid media were run parallel to those described above, except that the tests were continued for only four days. Experiment showed that at the higher temperatures the medium became considerably reduced by evaporation if left for a longer period.

TESTS ON LIQUID MEDIA.

In the series of tests on liquid media, all the species of which cultures had been obtained were grown on Cook's medium (see p. 41) both in tubes and in flasks, using ten tubes and six flasks at each temperature. The cultures of *Endothia gyrosa* and *E. singularis* were made with bits of mycelium from pure cultures. The other species were grown from conidia and the cultures were kept for two days at room temperature, in order to allow the conidia to germinate before being placed in the temperatures to be tested.

The following temperatures were used for making the tests: 40°, 37.5°, 35°, 29°, and 27°, and room temperature which was fairly constant at about 22°, 17°, 12°, 9°, 7°, 3°, and 2° C. There was some variation in the temperature of the incubators and refrigerators used, but in most cases they did not vary more than 1 degree above or below the temperature indicated. At 40° there were occasional traces of growth, especially in *Endothia parasitica*, but this may have occurred when the incubator dropped to 39° C. There is no regular and continued growth at this temperature.

At 37.5° C. there was perceptible growth in all the species. This is in striking contrast to the results on solid media, as no species grew at a temperature above 35° C. on solid media.

At 35° C. *Endothia parasitica* showed practically the same amount of growth as at 27° and 29° C. for the first three days, but fell behind after that. *E. fluens* showed less growth at 35° than at the lower temperatures. These two species were the only ones tested at 35° C.

At 27° and 29° C. growth was markedly more abundant than at 37.5°, and in most of the species was more abundant than at room temperature. In *Endothia gyrosa* and *E. fluens mississippiensis* the

growth at 27° C. was apparently equal to that at room temperature. At 22° C. (room temperature) all species developed much more rapidly than at the lower temperatures. At 17°, 12°, and 9° C. there was progressively less and less growth. At 7° C. and lower there was no growth whatever.

While these tests are not wholly satisfactory and must be regarded only as approximations, they are of some interest. Below 7° C. there is no growth in any species.

It is evident that there is a considerable range of temperature, from below 20° to well above 30° C., within which the species of *Endothia* grow readily. Within this range there may be a definite optimum for each species, but this has not yet been determined. For *Endothia parasitica* the optimum appears to be at 27° C. or above, and the same may be true of the other species.

At 40° C. or above no growth occurs. There is considerable evidence, however, that *Endothia fluens* is less resistant to the higher temperatures than either *E. parasitica* or *E. gyrosa*. After several of the tests the flasks were kept at room temperature for some days. It was found that all developed normally except those which had been kept at 40° and 37.5° C. These developed more slowly than those which had been kept at lower temperatures. It was particularly noticeable also that *E. parasitica* and *E. gyrosa* developed practically as well after being kept at 40° as at 37.5° C., while cultures of *E. fluens* which had been in 37.5° developed fairly well; but if kept at 40° for three days they entirely failed to develop.

DISTRIBUTION OF THE SPECIES OF ENDOTHIA.

During the past two years the writers have studied over 600 specimens of *Endothia* from various parts of the world. The greater number of these specimens have naturally come from the United States. The maps (figs. 1-4) show the known ranges of the various species in this country. Each dot on a map represents a locality from which the species has been collected. Frequently, of course, many specimens have come from a single locality; hence the number of dots by no means represents the number of collections.

In the case of *Endothia parasitica*, the dark portion represents the area over which the blight is practically continuous; that is, practically all the stands of chestnut are either diseased or dead. The dots represent known isolated infections and the solid line marks the botanical limit of the chestnut.

Endothia gyrosa is known only from the United States, but has a range in this country wider than that of any other species. As shown in figure 1, it has been found as far north as central Michigan, east to Connecticut, on the Pacific coast near San Francisco, and on

the Gulf of Mexico. There is, however, a very great difference in the abundance of this species at different points. In the southeastern United States—that is, the region south of central Indiana and southern Virginia and east of central Arkansas and Louisiana—this species occurs in great abundance wherever its hosts are found. Broken branch stubs and exposed roots of *Liquidambar*, *Fagus*, and *Quercus* are covered with fructifications of this fungus. This is especially true of roots exposed by erosion or excavation which have suffered mechanical injury through the tramping of men or cattle. Farther north in Maryland, New Jersey, and Connecticut only an occasional specimen is found. Three days' search in southern Con-

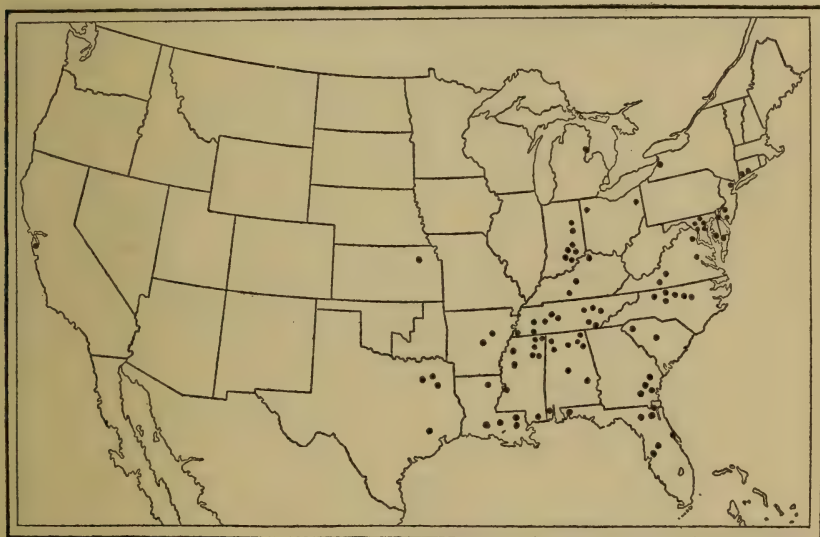


FIG. 1.—Outline map of the United States, showing the distribution of *Endothia gyrosa*.

necticut, for example, yielded only two specimens, both on *Liquidambar*, showing pycnidia only.

Endothia singularis is known at present only on oaks in the dry foothill regions of Colorado and New Mexico. Bethel, in a letter, states that it is very abundant in certain localities in Colorado.

Endothia fluens has long been known to occur in both Europe and America. Recently, through the kindness of Dr. Y. Kozai, director of the Central Agricultural Experiment Station, Nishigahara, Tokio, Japan, the writers received four specimens of fungi on chestnut. One of these, collected by S. Tsuruta on October 14, 1914, in the Province of Totomi, was the pycnidial stage of an *Endothia*, which when cultured proved to be *E. fluens*. Ascospore material of this species has since been collected by Meyer at Nikko, Japan, on the bark of *Pasania* sp.

Endothia fluens, while common to Europe, Asia, and America, has a much more limited range in the United States than *E. gyrosa*. It is fairly common on *Castanea* and *Quercus* from southern Pennsylvania and Ohio to northern Mississippi and Alabama. In southeastern Pennsylvania it has been found so far only on roots of *Quercus*, and in northern Mississippi and Alabama only on *Castanea dentata*.

Endothia fluens mississippiensis was first sent to the writers from Corinth, Miss., by Mr. T. E. Snyder, of the Bureau of Entomology, and has since been collected in only four other localities, three near the northeastern corner of Mississippi and one in central Kentucky.

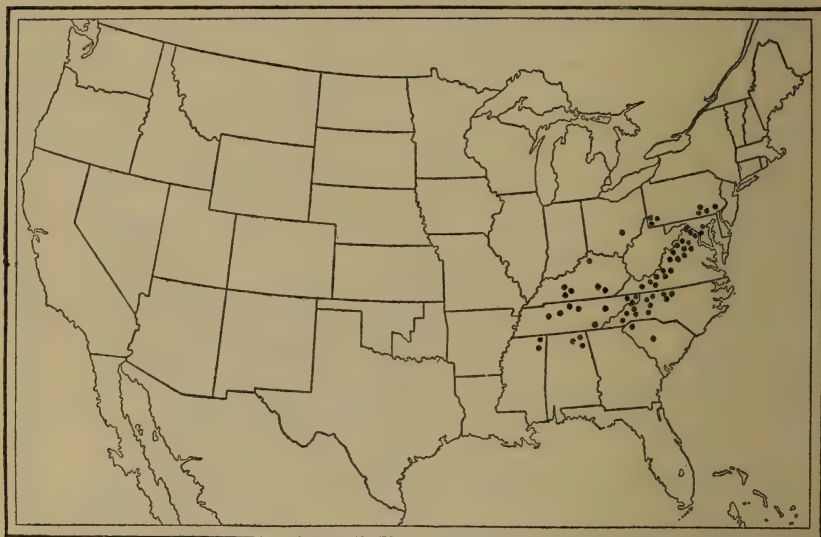


FIG. 2.—Outline map of the United States, showing the distribution of *Endothia fluens*.

As both *Endothia gyrosa* and *E. fluens* were collected in this country nearly a century ago by Schweinitz, it seems altogether probable that they are indigenous species which may have already reached the limits of their natural ranges in this country.

While the maps (figs. 1–4) do not give by any means every locality where *Endothia* is to be found and specimens are likely to be collected at many points outside the present known range, the writers feel justified in assuming that these maps represent the limits of the territory where *Endothia gyrosa* and *E. fluens* may commonly be found. This is especially true in the eastern portion, where the field has been rather thoroughly worked. It is unlikely, for instance, that *E. fluens* occurs abundantly in southern Alabama and Georgia, where *E. gyrosa* was found so commonly. Southeastern Pennsylvania must be somewhere near the northern limit for *E. fluens*, for the writers' four collections in that region are the result of six days'

search. At the northeastern limit of *E. gyrosa*, Clinton (15, p. 79) found only a single specimen after two years' search, and the writers have looked for it in all the other New England States without finding a single specimen. The report of *E. gyrosa* from Massachusetts by Hitchcock (42, p. 63) has already been shown to be a probable error in identification.

FACTORS INFLUENCING DISTRIBUTION.

HOST RELATIONS.

Just what determines the present ranges of the species can not, of course, be positively decided, but some relation to certain external factors may be traced. Neither species has the same distribution as

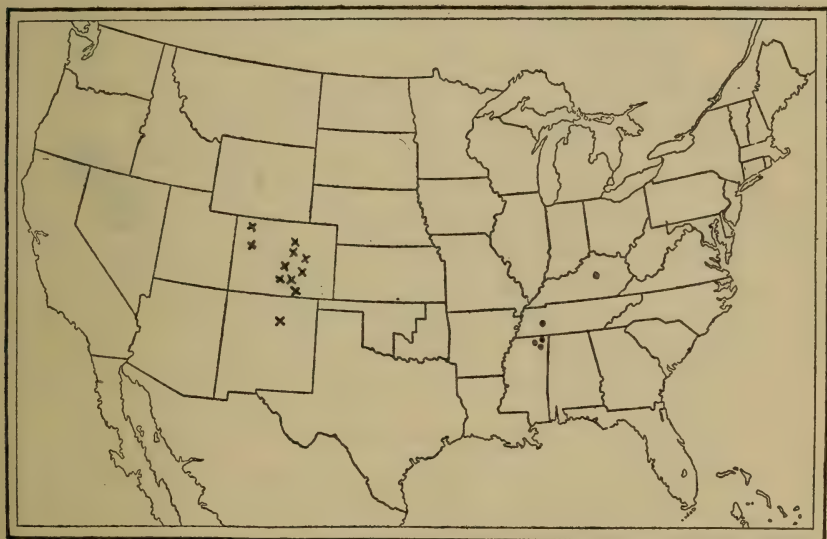


FIG. 3.—Outline map of the United States, showing the distribution of *Endothia fluens mississippiensis* and *E. singularis*. The dots indicate collections of *E. fluens mississippiensis* and crosses indicate collections of *E. singularis*.

its hosts. *Quercus* and *Fagus* are both abundant farther north than *Endothia gyrosa* has yet been found, while *Quercus* is abundant north and south of the known range of *E. fluens*. It may be worthy of note, however, that *E. gyrosa* extends north as far as *Liquidambar* is found. Perhaps more significant is the relation of the range of *E. fluens* to that of the chestnut. As will be seen from a comparison of the maps (figs. 2-4), *E. fluens* is not found abundantly at any point outside the natural range of the chestnut. Especially interesting is the fact that the southeastern limits of *E. fluens* and *Castanea dentata* are practically coincident, for in this region *Endothia fluens* was found only on *Castanea*, never on *Quercus*. This suggests the possibility that *Castanea* may be the original and favorite host of *Endothia fluens*.

SOIL CONDITIONS.

Greater opportunity for infection seems to be an important factor in the greater abundance of *Endothia* in the South. By far the most favorable places of infection, especially for *Endothia gyrosa*, are bruised or broken but still living roots. Soil, cultural, and climatic conditions combine to make these many times more abundant in the Southern States than elsewhere. The more sandy and easily eroded soil, usually without turf, subject throughout the winter to the action of wind and rain, leaves innumerable oak roots exposed, which are readily injured by vehicles and the tramping of horses and cattle, leaving wounds suitable for the entrance of *Endothia*. In the

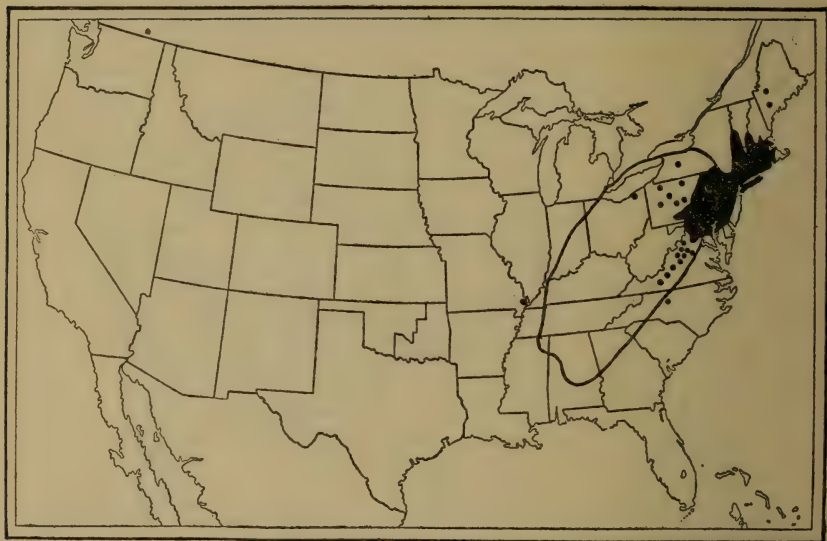


FIG. 4.—Map of the United States, showing the distribution of *Endothia parasitica* in December, 1915. The solid portion shows the area in which *E. parasitica* is generally present. The dots indicate scattered infections. The heavy line shows the limits of the range of *Castanea dentata*.

North, the more rocky soil, frequently covered with sod, protected through much of the winter by snow, makes exposed roots much less common, and the roots so exposed are rather less subject to mechanical injury. In the writer's experience the most favorable localities for collecting *E. gyrosa* are the unfenced public squares of Southern towns, where partial grading, erosion, and constant traffic have left hundreds of oak roots exposed, and the pastures of southwestern Indiana, where the roots of *Fagus* are often found injured by cattle.

COMPETITION AMONG FUNGI.

The writers' extensive field studies and observations have convinced them that competition among fungi must be considered as a

factor in determining their distribution. As already stated, while *Endothia fluens* occurs on *Quercus*, it has been found toward the southwestern limit of its range (northern Mississippi and Alabama) only on *Castanea*, and in Tennessee the writers have sixteen collections of this species on *Castanea* and only three on *Quercus*. In this same region, *E. gyrosa* is everywhere abundant on *Quercus*. In numerous inoculations with *E. gyrosa* and *E. fluens* on oak it has been found that *E. gyrosa* is more generally successful than *E. fluens*. Moreover, *E. gyrosa* occurs abundantly on *Liquidambar* and *Fagus* in this region, thus providing more numerous sources of infection for this species than for *E. fluens*. It seems highly probable, therefore, that *E. gyrosa*, with its greater affinity for oak and greater opportunity for infection, may occupy the available oak roots to the exclusion of *E. fluens*, even though climatic conditions are favorable for the growth of the latter species. *Castanea* rarely serves as a host for *E. gyrosa*; consequently, on this host *E. fluens* meets with little competition and is very abundant.

In the northeastern limit of its range, *Endothia fluens* has been found only on oak roots. Whether it grows naturally on chestnut in this region can not well be determined, since practically all the chestnut trees here are dead or badly diseased with *E. parasitica*. *E. gyrosa* is rare in this region, but *E. fluens* here evidently comes into competition with *Valsa frustum-coni* (Schw.) Curtis, which is common on exposed roots of various species of *Quercus*.

CLIMATE.

Since none of the species of *Endothia* in America extends to the limits of its host species, climate probably has an important part in determining their present ranges.

In this connection it is of interest to compare several life zone and climatic maps which have been published with the range maps of the various species of *Endothia*. The map entitled "Life zones of the United States," by C. Hart Merriam (50, pl. 14), is based largely on a study of animal life. Merriam deduces from his studies the conclusion that the northward distribution of animals and plants is determined by the total quantity of heat and their southern distribution by the mean temperature of the hottest part of the year. The life zones which he outlines show, however, a striking relation with the known ranges of *Endothia* in America. With the exception of a single locality for *Endothia gyrosa* in Michigan, all the known localities for *E. gyrosa* and *E. fluens* fall within the Upper Austral and Lower Austral zones. All the known localities for *E. fluens* and all the region where *E. gyrosa* has been found abundantly fall within the humid divisions of these zones. The northeastern limits of the Upper Austral coincide very closely with those of *E. gyrosa*; its

limits in Pennsylvania include the northern localities known for *E. fluens*, while the southern limits of this zone coincide closely with the southern limit of *E. fluens*.

The Livingstons (47) have published maps based on temperature summations and temperature efficiencies, as well as maps in which isoclimatic lines of temperature are combined with precipitation indices and evaporation indices for the mean frostless season.

While no very definite relations between these maps and the ranges of *Endothia* can be traced it is noteworthy that the localities where *Endothia gyrosa* is known to be abundant are all south of or near the 600 line of temperature efficiency, and only one collection of *E. gyrosa* has been made north of the 400 line. *E. singularis*, on the other hand, has thus far been found only north of the 400 line.

Zon's map (86) of vegetal regions of the United States is based on periods of growth and rest. The regions where *Endothia gyrosa* and *E. fluens* are abundant are all south of the line which marks the northern limit of seven months' vegetation. In fact this coincides very closely with the northern limit of *E. fluens*, and no specimen of *E. gyrosa* showing ascospores has been found farther north.

The relations pointed out above strongly suggest the possibility of some causal connection between climatic conditions and the present ranges of *Endothia* species, but just what factors may limit the spread of the species is not yet determined. The temperature tests recorded on pages 45 to 48 throw little light on this problem, for the maximum and minimum temperatures are about the same in the various species. *Endothia fluens* seems to be less resistant to the effects of high temperature (40° C.), but it is difficult to see that this fact alone has any direct bearing on the question of distribution.

DISCOVERY OF ENDOTHIA PARASITICA IN CHINA.

For eight years after its discovery in the New York Zoological Park in the summer of 1904, *Endothia parasitica* was known only from eastern North America. During this time two quite different opinions as to the origin of the fungus were advanced. Some investigators maintained that *E. parasitica* was an indigenous fungus (15); others that it had been imported from some foreign country, probably oriental (51, 52.) In the fall of 1912, however, pycnospore material was sent from Agassiz, B. C., by H. F. Güssow, Dominion Botanist of Canada. Cultures made from this material were identical with *E. parasitica*, and a series of inoculations on *Castanea dentata* produced typical cankers. Later, a large quantity of material collected at Agassiz by Dr. James R. Weir was received, which included a few ascospores. These proved to be typical *E. parasitica*.

A brief description of the identification of other specimens of *E. parasitica* from Agassiz is given by Faull and Graham (29). These writers report that in the material sent them in the summer of 1913 there were no perithecia, but that the pycospores were typical *E. parasitica* and the characteristic mycelial fans were present in the bark. Cultures of the fungus proved it to be identical with *E. parasitica*. They also state (p. 203) that the chestnuts grown at Agassiz "are of oriental, European, and American origin. The stock was purchased from nursery firms located in New Jersey, Ohio, and California. One of these at least 'was a heavy importer of oriental trees and shrubs'." They suggest that it "is significant that a connection with the Orient exists."

In support of this view, the statement of Mr. Sharpe, who had charge of planting the nut orchard at Agassiz, may be given. Dr. Weir visited Mr. Sharpe at Salmon Arm, B. C., and Mr. Sharpe stated definitely to him that he would be willing to furnish affidavit to the effect that in the main or entirely the chestnut trees in the nut orchard were originally imported from the Orient; in fact, a part of the trees, according to Mr. Sharpe, undoubtedly came from Japan or China and were shipped to Agassiz in the original wrappings, which consisted of the peculiar mats and casings of those countries.

In a letter accompanying the specimens from British Columbia Güssow states that "these trees may be regarded as absolutely isolated. There is no other chestnut tree anywhere round it for 500 miles and more." It seems highly probable therefore that *E. parasitica* was carried to this locality on nursery stock, perhaps as suggested by Faull and Graham and by Weir by importation from the Orient.

The following spring (1913) Mr. Frank N. Meyer, agricultural explorer, discovered this fungus in Chihli Province, China, under such conditions as could leave no doubt that it is indigenous there. The account of this discovery and its corroboration in this country was published by Fairchild (27), and also by the writers (76).

As outlined by Fairchild (27), Meyer first found the diseased chestnuts near Santunying, a small town $1\frac{1}{2}$ days journey by cart from a railroad, northeast of Peking in Chihli Province, between Tsunhua-tcho and Yehol.

A small specimen of diseased chestnut bark from this region was inclosed in a letter from Mr. Meyer which was received by Mr. Fairchild on June 28, 1913. From this specimen, which showed only pycnospores, cultures were obtained, which proved it to be true *E. parasitica*. On July 23 more Chinese specimens were received from the same locality, as well as from Scha Ho in the same Province. These included a large canker on a chestnut branch about 6 cm. in

diameter, which agreed in every respect with cankers produced on varieties of Japanese chestnuts in this country (Pl. XXII).

Other specimens in this collection showed well-developed perithecia and ascospores. The ascospore measurements made at the time, as well as the cultures of the Chinese fungus and the inoculation experiments on *C. dentata*, are described in the previous paper by the writers (76, p. 296).

Shortly after this first series of inoculations was made subcultures of the Chinese material were sent to several investigators who had been studying the chestnut-bark disease, in order that the *Endothia* from China might be tested as soon as possible under American conditions by inoculations at various points throughout the known range of the disease.

A series of inoculations was made by Prof. J. Franklin Collins at Martic Forge, Pa., on July 14, 1913, using American and grafted Paragon and grafted Japanese chestnut trees. Another series of inoculations, 56 in number, was made at the same locality September 10, 1913, by Dr. Caroline Rumbold on grafted Paragon chestnuts. Twenty inoculations were made on native chestnuts at Anderson, Pa., October 2, 1913, by Dr. F. D. Heald and R. A. Studhalter. Inoculations with the Chinese *Endothia* were made at Leesburg, Va., on both *Castanea dentata* and *C. pumila* by G. Flippo Gravatt and J. T. Rogers, August 16, 1913.

All these investigators made duplicate inoculations with American material, and all agreed that the Chinese fungus was identical in its effects on the host with the American chestnut-blight fungus. During the season of 1914 numerous inoculations with material from China were made by the writers at various points in New Hampshire, Massachusetts, Connecticut, New York, Delaware, and Maryland, while others have been made in Rhode Island by Prof. Collins with the same results.

ADDITIONAL CHINESE SPECIMENS.

Since the publication of the previous paper (76) additional specimens of *E. parasitica* from China have been received from Meyer; one collected at Changli, Chihli Province, China, October 13, 1913, by Mrs. Mary S. Clemens; a quantity of material collected by Meyer himself in the village of Tachingko, near Taianfu, Shantung, China, March 21, 1914; and another collected by him at Yatyeko, Shensi, China, September 2, 1914. A few cankers have also been sent by Meyer, collected by him at Shihbonshan, near Hangchow, Chekiang Province, China, June 26, 1915. The label on this specimen bears the further comment, "very destructive in this locality." Cultures have been made from all these specimens and have invariably proved to be identical with cultures of *E. parasitica* found in this country.



AN OLD CANKER CAUSED BY ENDOTHIA PARASITICA ON A BRANCH OF CASTANEA MOLLISSIMA.

Collected by Frank N. Meyer, May 31, 1913, near Santunying, Chihli Province, China.

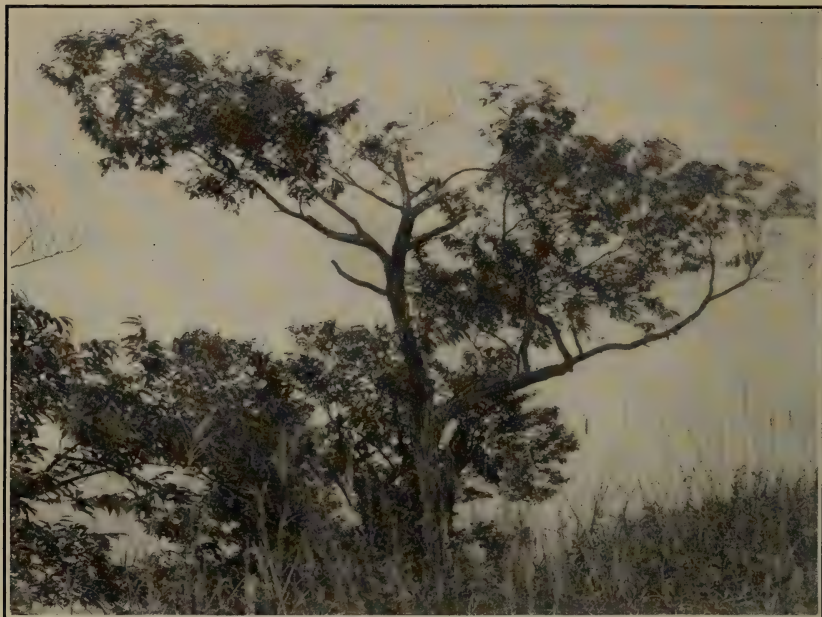


FIG. 1.—JAPANESE CHESTNUT AT NIKKO, JAPAN, FROM WHICH THE CHESTNUT BLIGHT FUNGUS (*ENDOTHIA PARASITICA*) WAS COLLECTED BY F. N. MEYER, ON SEPTEMBER 17, 1915.



FIG. 2.—TWO BRANCHES OF A JAPANESE CHESTNUT. THE LARGER (TO THE LEFT) WAS BROUGHT TO THIS COUNTRY BY F. N. MEYER, AND FROM IT *ENDOTHIA PARASITICA* WAS ISOLATED.

As Tachingko is 300 miles south of Changli, where *E. parasitica* was first collected by Meyer, and Yatyeko is 500 miles west of Tachingko, it seems highly probable from the collections that *E. parasitica* is widely distributed in China (fig. 5).

Meyer, writing from Hangchow, July 1, 1915, refers as follows to the condition of the chestnuts in that locality:

Well, I have a few interesting discoveries to report. First, there are many specimens of *Castanea mollissima* scattered at the bases and on the lower slopes of the hills around here, and these chestnuts are seriously attacked by the bark fungus, and in my estimation are going to succumb to it these coming years. The chinquapins (*Castanea* spp.), however, which are very abundant on the higher and more sterile hill slopes, seem to be immune;



FIG. 5.—Outline map of China and Japan, showing the localities in which *Endothia parasitica* has been found.

at least I did not see any evidences of damage or even of attacks. This brings another interesting point to my mind. I was told in Nanking that various missionaries at Kuling, the great summer resort in central China for missionaries, were cutting down their chestnuts, as the tops were all dying, due to borers working underneath the bark.

Meyer has since stated to the writers that he believes the destruction of the chestnut at Kuling is due to *Endothia parasitica* rather than to borers.

In the writers' earlier publication the following statement was made (76, p. 297):

The Chinese organism has thus been shown to be practically identical with the American in all its morphological and physiological characters and in the production of the typical chestnut blight and the pycnidial fructifications

of the fungus. There is apparently but one other requirement that could be made according to the strictest pathological canons to perfect the proof in this case, and that is the production of typical ascospores of *E. parasitica* on the lesions produced by the inoculations.

The last requirement has now been fulfilled. Specimens collected February 15, 1915, from inoculations made September 20, 1913, on chestnuts in Virginia, near Point of Rocks, Md., with Chinese material, show perithecial stromata with typical ascospores of *E. parasitica*, thus completing the evidence.

DISCOVERY OF *ENDOTHIA PARASITICA* IN JAPAN.

More than two years after his original discovery of *Endothia parasitica* in China (June 3, 1913), Meyer also discovered the fungus in Japan. A brief account of his discovery has already been published by the writers (78). It may be sufficient here to state that following the discovery of *Endothia parasitica* in China the writers endeavored by correspondence to obtain the fungus from Japan. While not successful in obtaining *Endothia parasitica*, the writers did receive several specimens of fungi, including species of *Endothia* on species of *Castanea*. These, together with several specimens of fungi found on chestnut nursery stock from Japan, make it clear that there are in that country several *Pyrenomycetes* other than *Endothia parasitica* more or less parasitic on *Castanea*.

Meyer first discovered the chestnut-blight fungus in Japan at Nikko, September 17, 1915, on wild trees of *Castanea crenata* Sieb. and Zucc. A photograph of the trees from which he collected specimens of *Endothia parasitica* is shown in Plate XXIII, figure 1, and a branch from which the diseased material brought to the United States was taken is shown in Plate XXIII, figure 2.

Shortly after Meyer's arrival in Washington in December, 1915, the specimens collected at Nikko were turned over to the writers for study. Examination at once showed cankers and mycelial fans typical of *Endothia parasitica*. The material also contained typical pycnosporos and ascospores of the fungus. Cultures made from single ascospores on various culture media proved to be identical with those of *Endothia parasitica* found in this country and in China, thus establishing beyond question the identity of the fungus.

Meyer's observations as to the resistance of the Japanese chestnuts to this disease are of great interest. He states that the trees vary considerably as regards their power of resistance, but that in general the Japanese chestnut is even more resistant to *Endothia parasitica* than is the Chinese chestnut (*Castanea mollissima*).

As announced in the same publication (78), *Endothia parasitica* was collected by Dr. Gentaro Yamada at Morioka, northern Japan. These specimens, which show typical cankers as well as ascospores of the fungus, were received by the writers on January 8, 1916.

PRESENT DISTRIBUTION OF ENDOTHIA PARASITICA IN AMERICA.

The present range of *Endothia parasitica* in America, as shown by the map (fig. 4), is probably merely the extent to which it has been able to spread in the time since it was first introduced.

Whether *Endothia parasitica* was introduced into one locality or several is uncertain, but the studies of Heald (40, 41) and others have shown clearly that the spores of *E. parasitica* are carried by the wind, by insects and birds, and on nursery stock, which would account for its wide distribution and for its occurrence in isolated localities, long distances away from the main body of the disease. It also makes it seem probable that the fungus will continue to spread with some rapidity.

Certainly, there is no evidence that any factor, climatic or otherwise, is likely to prevent the spread of this fungus into the large area of chestnut south of its present range. On the contrary, the duplicate inoculations made by the writers show clearly that the fungus grows more rapidly at the southern limit of its present range than farther north, where it is much more common. The longer growing season in the South is also no doubt an important factor.

In this connection, it may be noted that Köppen (46), in his map of the vegetation regions of the earth, places the portion of China where *Endothia parasitica* has been found indigenous in the same climatic region as that portion of the United States where it is now doing such destructive work. He designates this region as the "Hickory" division of the mesotherms.

HOST RELATIONS OF THE SPECIES OF ENDOTHIA.

ENDOTHIA GYROSA.

Endothia gyrosa occurs commonly on Liquidambar, Fagus, and Quercus, occasionally on Castanea, and has been found on Vitis in Alabama, but the writers were unable to obtain fresh material from this host.

While Fagus and Quercus are, of course, closely related, it seems remarkable that a fungus should be abundant on hosts so different as Liquidambar and Quercus, yet so rare on any other host as to be only once reported. It seemed possible, indeed, that the fungus on Liquidambar, while morphologically and culturally identical with that on the various other hosts, might prove to be physiologically different. In order to obtain more definite information on this point, several series of cross inoculations were made.

It had been observed that *Endothia gyrosa* was found most frequently on the cut or broken ends of branches or on exposed, bruised, or broken roots. In making inoculations, therefore, a small branch,

1 inch or less in diameter, was cut off about 6 inches from the main trunk. Mycelium from corn meal in flasks was placed on the cut end of the stub and covered with wet cotton, over which oiled paper was tied. In about two weeks the paper and cotton were removed. In all cases branches similar to those inoculated were cut as checks.

TABLE III.—*Inoculations with Endothia gyrosa.*

Source of fungus and date.	Host inoculated.	Number of inoculations.	Number successful.	Remarks.
Fagus:				
May 8, 1913.....	Castanea.....	6	3	Pycnospores first observed on Oct. 16.
May 29, 1913.....	Fagus.....	3	3	Pycnospores first observed on Aug. 29 for two and on Oct. 10 for the third.
Sept. 15, 1913.....	Liquidambar.....	5	2	No growth until the spring of 1914; pycnidia scattered and small on Oct. 13.
Do.....	Quercus.....	4	2	No growth until spring; well developed on Oct. 13, 1914.
Apr. 2, 1914.....	Fagus.....	4	0	
Do.....	Quercus.....	4	0	
Do.....	Castanea.....	4	2	Pycnidial stromata well developed on Oct. 13, 1914.
May 23, 1914.....	do.....	4	4	Do.
Do.....	Liquidambar.....	4	0	
Do.....	Quercus ¹	4	0	
Do.....	Fagus.....	4	3	Do.
Quercus:				
May 29, 1913.....	do.....	3	3	Pycnospores first observed on Aug. 29, 1913.
Do.....	Liquidambar.....	4	2	Very slight indications of growth on Aug. 29, 1913; a few pycnidia with spores on Oct. 16.
Sept. 15, 1913.....	do.....	8	0	
Do.....	Castanea.....	4	2	Large well-developed pycnidia on Oct. 13, 1914.
Apr. 2, 1914.....	Fagus.....	4	0	
Do.....	Quercus ¹	4	0	
Do.....	Castanea.....	4	4	Large abundant pycnidial stromata on Oct. 13, 1914.
May 23, 1914.....	do.....	4	4	Abundant well-developed pycnidial stromata on Oct. 13, 1914.
Do.....	Liquidambar.....	4	0	
Do.....	Quercus ¹	4	0	
Do.....	Fagus.....	4	3	
Castanea:				
May 29, 1913.....	do.....	3	3	Pycnospores first observed on Aug. 29, 1913.
Do.....	Liquidambar.....	3	3	Slight indications of pycnidial formation on Aug. 29, 1913; pycnospores on all on Nov. 17, 1913.
Apr. 2, 1914.....	Fagus.....	4	0	
Do.....	Quercus ¹	4	1	Large well-developed pycnidial stromata on Oct. 13, 1914.
Do.....	Castanea.....	4	3	Scattered, fairly well-developed pycnidia on Oct. 13, 1914.
May 23, 1914.....	do.....	4	4	Abundant well-developed pycnidia on Oct. 13, 1914.
Do.....	Liquidambar.....	4	0	
Do.....	Quercus ¹	4	0	
Liquidambar:				
May 29, 1913.....	Fagus.....	3	0	
Do.....	Liquidambar.....	3	3	Pycnospores first observed on Aug. 29.
Sept. 15, 1913.....	Fagus.....	8	5	No evidence of growth until the spring of 1914; pycnidia few and small on Oct. 13.
Do.....	Castanea.....	6	2	No growth until the spring of 1914; pycnidia small on Oct. 13.
Do.....	Quercus.....	6	0	
Apr. 2, 1914.....	Fagus.....	4	0	
Do.....	Quercus ¹	4	0	
Do.....	Castanea.....	4	0	
May 23, 1914.....	do.....	4	0	
Do.....	Liquidambar.....	4	4	Abundant pycnidia on Oct. 13, 1914.
Do.....	Quercus ¹	4	0	
Do.....	Fagus.....	4	0	

¹ The species used in this case was *Quercus prinus*, which proved to be an exceedingly unfavorable host for *Endothia gyrosa*.

Inoculations with *Endothia gyrosa* were also made on numerous hosts from which it had never been reported. Six or more inoculations were made on each host, in the manner described above, except that a part of each series was left unwrapped. The following inoculations showed no growth whatever: Those made in Virginia, April 4, 1914, on *Cornus florida*, *Fraxinus americana*, *Juglans cinerea*, *Ilex opaca*, *Sassafras variifolium*; in Maryland, April 17 and 22, 1914, on *Carya glabra*, *Cornus florida*, *Liriodendron tulipifera*, *Nyssa sylvatica*, *Sassafras variifolium*, and *Quercus alba*; and in New York, July 11, 1914, on *Betula alba*, *Prunus serotina*, *Populus tremuloides*, *Rhus glabra*, *Salix* sp., and *Sassafras variifolium*. On *Acer pennsylvanicum* and *Carya* two out of the six inoculations developed a few stromata. These were found only on the tissue injured by the cut and there was no evidence of parasitism.

On *Castanea*, *Fagus*, *Quercus*, and *Liquidambar*, however, a branch inoculated as described above dies back rather faster than the checks. This would indicate, as suggested by Clinton (18, p. 419), that *E. gyrosa* is a weak parasite; that is, that it is able to invade injured and dying tissue.

It is evident from Table III that *Endothia gyrosa* coming from any of the four hosts named will, under favorable circumstances, grow on any of the others. Several other interesting facts are brought out by the table. Inoculations made with material from *Liquidambar* grew in general more rapidly on *Liquidambar* than on any of the other hosts. In many cases, material from *Liquidambar* failed to grow on *Castanea*, *Fagus*, and *Quercus*, and even when inoculations were successful growth was somewhat slower and pycnidial production less abundant.

On the other hand, inoculations from *Fagus*, *Quercus*, and *Castanea* usually grew less rapidly on *Liquidambar* than on any of the other three hosts. This is, of course, what would be expected from the systematic relationships of the host species, and while the inoculations made are too few to permit any definite conclusions they are nevertheless suggestive. As shown by Table III, *Quercus prinus* proved a very unfavorable host for *Endothia gyrosa*.

In all cases inoculations made in the fall (Sept. 15) failed to show any growth until the following spring. This corresponds with the results in inoculations of *Endothia parasitica*, but it is, of course, impossible to determine whether this failure to grow is due to the dormant condition of the host or to unfavorable weather conditions. Perhaps correlated with the results just noted are the unusually poor results obtained from inoculations made in the early spring. It will be noted that inoculations made on April 2, 1914, were in general much less successful than those made on May 23, 1914, in exactly the same locality and in many cases on the same hosts.

ENDOTHIA SINGULARIS.

The material of *Endothia singularis* distributed by Sydow as *Calopactis singularis* was on *Quercus gambellii* Nutt. The writers have seen abundant material on this species as well as specimens on *Q. utahensis* (A. DC.) Rydb., *Q. leptophylla* Rydb., and *Q. nitescens* Rydb. Specimens on the latter two hosts were sent by Bethel, who, in a letter, reports finding this species also on *Q. pungens* Liebm.

All of these species except *Quercus leptophylla* are chaparral-forming shrubs growing at an elevation of 4,000 feet or more. There is at present no evidence that the fungus is parasitic on any of the species.

Inoculations with the mycelium of *Endothia singularis* were made on *Fagus* and on *Quercus alba*, *Q. velutina*, *Q. rubra*, and *Q. palustris*, as well as on *Q. ilicifolia* on Overlook Mountain in the Catskills. No growth has, however, been noted in any case.

ENDOTHIA FLUENS.

When these investigations were commenced, the writers thought that the *Endothia* found in Europe might be the same as *Endothia parasitica* found in America. Inoculations were accordingly made in Maryland during October, 1912, with cultures from material collected on the chestnut by the senior writer at Stresa, Italy, and Etrembieres, Switzerland, using material of *E. fluens* sent by P. J. Anderson from Pennsylvania; also material of that species and of *E. parasitica* collected in Virginia as checks. In this case, as in all others where no special mention is made of the method, inoculations were made by cutting through the bark to the wood with a sharp knife. The inoculating material was then inserted with a freshly cut twig and the wound tied up either with cord or rubber bands. If cord was used it was cut away within two to four weeks. The rubber bands became loosened by exposure to the weather within about the same time.

Inoculations were made with all the above material on sprouts of *Castanea dentata* and *Quercus prinus*. The results are summarized in Table IV.

TABLE IV.—Inoculations of *Endothia* in Maryland in October, 1912.

Fungus.	Host inoculated.	Number of inoculations.	Number showing growth.
<i>Endothia parasitica</i>	<i>Castanea dentata</i>	32	28
Do.....	<i>Quercus prinus</i>	6	0
<i>E. fluens</i> :			
European.....	<i>Castanea dentata</i>	14	14
American.....	do.....	26	23
Do.....	<i>Quercus prinus</i>	12	9

The inoculations were examined every 10 days until December 1 and monthly thereafter throughout the winter. There was no perceptible growth until the last of April, when several of the inoculations of *Endothia parasitica* showed slight sunken areas. By May 20 all inoculations checked as showing growth (last column of table) showed the slight yellowish elevations of the bark which indicate the beginnings of pycnidia. On August 30 all the inoculations of *E. parasitica* checked as showing growth had spread rapidly and attacked the living tissues of the host, producing typical cankers with mycelial fans and abundant pycnidia.

No signs of growth were noted in the inoculations of *Endothia fluens* until about the middle of May, 1913, when most of them showed signs of pycnidium formation. By August 30 all those marked as showing growth had produced characteristic pycnidia with spores, which when cultured proved to be typical *E. fluens*. In no case, however, did this fungus spread for any appreciable distance beyond the injured portion or show signs of active parasitism. These results agree with those given by Anderson and Anderson (2, p. 206) with American material of *E. fluens*, and have since been fully confirmed by further observation.

During the summer of 1914 about 1,100 inoculations of *Endothia fluens* from both European and American sources and of *E. fluens mississippiensis* were made on Castanea sprouts. In no case was there any evidence of active parasitism, as in *E. parasitica*.

Although *Endothia fluens* has been found in Europe on a considerable number of deciduous host plants (as recorded on p. 18), the writers have thus far failed to find it in this country on any except Castanea and Quercus. It seemed possible that the European strain of the fungus might be somewhat more plurivorous¹ in its habits than the American. In order to throw some light on this point, the following inoculations were made:

On March 31, 1914, 10 inoculations were made, half of European and half of American material, at Francis, Md., on the following hosts: *Alnus rugosa*, *Betula nigra*, *Carpinus caroliniana*, *Carya glabra*, *Fagus grandifolia*, *Liriodendron tulipifera*, and *Liquidambar styraciflua*. Pycnidia appeared only on *Carya glabra* and *Carpinus caroliniana*. Of the inoculations which actually produced pycnidia, four on *Carpinus* and three on *Carya*, one of each was the European strain.

On April 22 inoculations were made with American material of *E. fluens* at Kensington, Md., on *Acer rubrum*, *Carya glabra*, *Cornus florida*, *Fagus grandifolia*, *Prunus serotina*, *Quercus prinus*, *Sassafras variifolium*, *Vaccinium* sp.,

¹ This term is proposed to apply to fungi occurring on two or more hosts or substrata and may be applied to all fungi except true parasites. It is derived from *plus* (plur-), more, and *vorare*, to devour. Compare omnivorous already in use for fungi.

The term pleioxonous might be derived from De Bary's proposed word pleioxony and applied to true parasites having the power to invade more than one species of host plant, and the term plurivorous restricted to nonparasitic organisms.

and *Vitis* sp. Of these, *Acer rubrum* and *Carya glabra* gave numerous small pycnidia.

On July 10 the following hosts were inoculated at Woodstock, N. Y., with *E. fluens* from Europe: *Acer rubrum*, *A. pennsylvanicum*, *Carya ovata*, *Corylus americana*, *Fraxinus americana*, *Hamamelis virginiana*, *Kalmia latifolia*, *Populus grandidentata*, *Prunus serotina*, *Rhus glabra*, *Salix* sp., *Sassafras variifolium*, and *Syringa vulgaris*. Each host was inoculated in six or seven places, but all failed to develop except two inoculations on *Acer pennsylvanicum* and one on *Corylus americana*.

The results cited above are so largely negative that they prove very little except that the European strain shows no special affinity for these hosts in America.

ENDOTHIA FLUENS MISSISSIPPIENSIS.

Only five collections of *Endothia fluens mississippiensis* have thus far been made, three on *Castanea dentata* and two on *Quercus* sp. From the results of the inoculations its host relations appear very similar to those of *E. fluens*. The results are shown in Table V.

TABLE V.—Inoculations with *Endothia fluens mississippiensis* on *Castanea* and *Quercus*.

Source of culture.	Host inoculated.	Date.	Number of inoculations.	Number showing pycnidia.
Castanea.....	Castanea.....	Jan. 20, 1912	8	8
Do.....	do.....	May 8, 1913	4	4
Do.....	do.....	do.....	4	4
Do.....	Quercus prinus.....	do.....	9	7
Do.....	Castanea.....	Apr. 18, 1914	12	10
Quercus.....	do.....	do.....	12	10

The inoculations of January 20, 1912, showed no signs of growth until early in May, when the first signs of pycnidium formation were observed. The inoculations with *Endothia fluens mississippiensis* made May 8, 1913, showed within three weeks discolored areas near the cut which were larger than those about the check cuts. On July 25, 1913, all of the inoculations of *E. fluens mississippiensis* marked "successful" showed the beginnings of pycnidium formation. By August 30, 1913, they were producing pycnosporos, which when cultured proved to be *E. fluens mississippiensis*.

Inoculations were made in April, 1914, for the purpose of comparing the material collected on oak with that collected on chestnut. No difference was detected, and there was no indication of active parasitism. This form behaved in this respect exactly as did the *E. fluens* from Virginia both on *Castanea dentata* and *Quercus prinus*.

A series of inoculations parallel to that made with *E. fluens* was made with *E. fluens mississippiensis*. The same hosts were used, and in most cases the dates and places of the inoculation were the same. The results of all that showed any growth are given in Table VI.

TABLE VI.—Inoculations with *Endothia fluens mississippiensis* on *Acer* and *Carya*.

Location.	Host.	Number of inoculations.	Number showing pycnidia.
Woodstock, N. Y.....	<i>Acer rubrum</i>	6	3
Do.....	<i>Carya glabra</i>	6	2
Francis, Md.....	do.....	6	1
Kensington, Md.....	<i>Acer rubrum</i>	1	1
Do.....	<i>Carya glabra</i>	2	2

As in *Endothia fluens* the growth was confined to the injured tissues, and there was no evidence of parasitism.

ENDOTHIA TROPICALIS.

The material of *Endothia tropicalis* from which the writers secured their cultures, was collected by T. Petch in Ceylon. As the species of *Endothia* in the Northern Hemisphere are chiefly on members of the Fagaceæ, Petch's statements with regard to hosts are of considerable interest. In a letter of March 6, 1914, he writes:

We have no Fagaceæ native in the island. We have introduced various species of *Quercus* and *Castanea*, but subsequent to Thwaite's discovery of this fungus. I do not think there can be any doubt that the fungus is native to Ceylon * * *

Of the specimens now sent * * * those in the packet * * * are from a tree which was producing shoots from the base. This tree is *Elaeocarpus glandulifer* Mast. From the bark and habit, I believe that all my "finds" of *Endothia* have been on this species.

In the accounts of the American chestnut disease, I notice that several authors speak of "cankers," and give their rate of growth. I never see "cankers" (Krebs) on the Ceylon trees. The bark appears to die regularly and smoothly from above downward, and is quite unbroken except for the minute cracks through which the stromata emerge.

Inoculations.—As already noted, ascospores of *Endothia tropicalis* resemble those of *E. parasitica* even more closely than do those of *E. fluens*. This fact, together with its similarity on culture media and its oriental origin, led the writers to fear possible parasitic tendencies.

Inoculation experiments were accordingly made only on the chestnut and under carefully guarded conditions. In all, about 30 inoculations were made on 2-inch chestnut sprouts, using the methods described for other species.

Of 25 inoculations made in May and June, practically all had developed a few pycnidial stromata by October 20. These stromata were a somewhat brighter orange than those of *E. fluens* or *E. fluens mississippiensis*, and the spores when cultured produced typical *E. tropicalis*. In no case, however, was there any evidence of parasitism.

ENDOTHIA PARASITICA ON HOSTS OTHER THAN CASTANEA.

The first collection of *Endothia parasitica* on a host other than *Castanea* of which the writers have any knowledge is that made by J. Franklin Collins at Martic Forge, Pa., June 30, 1909. As announced by Dr. Metcalf at the Boston (December, 1909) meeting of the American Phytopathological Society, the specimen consisted of a small dead branch of *Quercus velutina* with several spore tendrils typical of *E. parasitica*. This material, which consisted of a terminal branch with leaves still retained, was at once sent to the laboratory at Washington, and cultures obtained from it were subsequently used in making numerous inoculations on *Castanea dentata* on Long Island, N. Y., in July, 1909. On November 17 of the same year, Metcalf reported that the inoculations were entirely successful and had produced typical lesions, thus establishing without question the identity of the fungus.

Fulton (37, p. 53) reports *E. parasitica* on the dead bark of *Quercus alba* and *Quercus velutina*, but found no evidence that the fungus produces in any sense a disease of such trees. Clinton (18, p. 428) mentions cultures from three different species of *Quercus* and (p. 376) reports specimens on *Quercus alba*, *Q. rubra*, and *Q. velutina*.

Anderson and Babcock, as quoted by Anderson and Rankin (6, p. 564), found *Endothia parasitica* on *Quercus velutina*, *Q. alba*, *Q. prinus*, *Rhus typhina*, *Acer rubrum*, and *Carya ovata*, but it seemed parasitic only on *Quercus alba*. They made inoculations with materials isolated from *Castanea* on *Quercus prinus*, *Q. velutina*, *Q. alba*, *Q. coccinea*, *Rhus typhina*, *Acer rubrum*, *Liriodendron tulipifera*, and *Carya ovata*. Two trees of *Rhus* were girdled and killed by the growth of the fungus. On *Quercus alba* the fungus seemed slightly parasitic, but none of the trees were killed. The fungus grew and produced spore horns on the wounded tissue near the point of inoculation on all the hosts except *Acer* and *Liriodendron*.

Rankin (62, p. 238) also made inoculations with *Endothia parasitica* from *Castanea* on *Quercus prinus*, *Q. rubra*, *Q. alba*, and *Q. coccinea*. He found that the mycelium advanced into the living tissues for a short distance in a few cases, but that in no case were typical cankers formed. Pycnidia were produced abundantly on the injured tissues of all the hosts.

During the course of this work only four specimens of *Endothia parasitica* on hosts other than *Castanea* have come to the writers. One was on chestnut oak (*Quercus prinus*) collected by F. W. Besley, at Towson, Md., December 26, 1911; one from *Quercus velutina*, at Germantown, Pa., as well as one from white oak (*Quercus alba*), at Kennett Square, Pa., were collected by S. B. Detwiler; and one from dead maple, *Acer* sp., at Florence, Mass., by Roy G. Pierce.

The specimen collected by Besley on *Quercus prinus* showed the fan-shaped mats of mycelium typical of *E. parasitica* on *Castanea* species. The fungus had apparently girdled the tree. The specimen on *Quercus alba*, collected by Detwiler, was similar to one on *Quercus prinus* in appearance and came from a dead tree which had apparently been killed by the growth of the fungus. The specimens on *Acer* sp. and on *Quercus alba* were received in the spring of 1914, and cultures isolated from them were used in making inoculations for the purpose of determining whether the fungus had either lost or gained in virulence by passing through other hosts.

INOCULATION EXPERIMENTS.

The cultures secured from *Acer* and *Quercus*, together with one made from *Castanea* at about the same time, were inoculated into three separate sprouts of *Acer rubrum*, *Castanea dentata*, and *Quercus prinus*. The sprouts chosen were of nearly the same size, 2 inches in diameter, and similarly situated, and each was inoculated in five places, with two check cuts above. The inoculations were made the usual way on March 31, 1914, and were examined at least once a month during the summer.

None of the inoculations on *Quercus* produced any growth whatever. On *Acer* the inoculations with the culture from *Quercus* all failed to develop; one of the inoculations with the culture from *Acer* showed a few pycnidia, while four of the inoculations with material from the chestnut developed a few pycnidia. On *Castanea* the three series of inoculations were almost identical, every inoculation producing a typical canker.

Of course, these inoculations are too few to be conclusive, but it is evident that there was no decrease in virulence on the chestnut in passing through *Acer* or *Quercus* and that no particular affinity for either *Acer* or *Quercus* was gained. On the maple, in fact, the culture direct from chestnut produced the most growth.

In addition to those listed above, numerous inoculations were made in order to determine whether *Endothia parasitica* had any parasitic tendencies on other deciduous hosts.

These inoculations were all made during the spring of 1914 by the usual method of cutting well through the bark and inserting mycelium and spores from a pure culture, usually on corn meal. The wounds were then wet, some bound with wet cotton, others with paraffin paper, and about half were left unwrapped.

Seven or more inoculations were made on April 4 in Maryland on *Alnus rugosa*, *Betula nigra*, *Carpinus caroliniana*, *Fagus grandifolia*, *Kalmia latifolia*, *Liriodendron tulipifera*, and *Liquidambar styraciflua*, none of which developed. Inoculations were also made on April

22 in this locality on *Acer rubrum*, *Carya glabra*, *Cornus florida*, *Fagus grandifolia*, *Liriodendron tulipifera*, *Quercus prinus*, *Sassafras variifolium*, *Vaccinium* sp., and *Vitis* sp. without success. On April 18, the following hosts were inoculated in Virginia: *Acer rubrum*, *Betula nigra*, *Benzoin aestivale*, *Carpinus caroliniana*, *Carya glabra*, *Cornus florida*, *Fagus grandifolia*, *Liriodendron tulipifera*, *Prunus serotina*, *Quercus alba*, *Ulmus americana*, and *Vitis* sp. Each host was inoculated in from four to six places. Of these, pycnidia were produced only on *Acer rubrum*, *Carpinus*, and *Liriodendron*. A similar series was made on the same hosts in the same place on May 27. Inoculations on one tree of *Quercus alba* showed undoubted evidence of parasitism and is described below.

On July 9 and 11 from five to fourteen inoculations were made on each of the following hosts at Woodstock, N. Y.: *Acer rubrum*, *Betula alba*, *Carya ovata*, *Fagus grandifolia*, *Fraxinus americana*, *Hamamelis virginiana*, *Juglans cinerea*, *Kalmia latifolia*, *Nyssa sylvatica*, *Ostrya virginiana*, *Populus grandidentata*, *Prunus serotina*, *Rhus typhina*, *Quercus rubra*, *Salix* sp., *Sambucus canadensis*, and *Sassafras variifolium*. Pycnidia appeared on *Acer rubrum* and *Ostrya* only. The fungus made considerable growth on two plants of *Rhus typhina*, partly girdling branches one-half inch in diameter and producing distinct fans. The fans were, however, much smaller than those usually found in *Castanea*. Inoculations were made at Avon, Conn., July 15, on *Acer saccharum*, *Betula alba*, *Carya glabra*, *Cornus florida*, and *Ostrya virginiana*. Pycnidia developed only on *Ostrya*. The successful inoculations with *Endothia parasitica* are shown in Table VII.

TABLE VII.—Successful inoculations in 1914 with *Endothia parasitica* on hosts other than *Castanea*.

Locality.	Date.	Host.	Number of inoculations.	Number successful. ¹
Virginia.....	Apr. 18	<i>Acer rubrum</i>	9	7
Do.....	do.	<i>Carpinus caroliniana</i>	6	2
Do.....	do.	<i>Liriodendron tulipifera</i>	6	1
Do.....	May 27	<i>Quercus alba</i>	4	4
New York.....	July 11	<i>Acer pennsylvanicum</i>	14	4
Do.....	do.	<i>Ostrya virginiana</i>	6	2
Connecticut.....	July 15	do.....	15	4

¹ Inoculations producing pycnidia are classed as successful.

It must be noted that while pycnidia were produced in the cases listed as successful, there was no indication of parasitism, nor did the growth extend beyond the tissue injured by the cut except in *Quercus* and *Rhus*.

Out of about 400 inoculations with *Endothia parasitica* on hosts other than *Castanea*, about 70 of which were made on different

species of *Quercus*, chiefly *Q. prinus* and *Q. alba*, only one case has been noted in which the fungus assumed a typically parasitic rôle. The data in this case may be summed up as follows: Four inoculations were made May 27, 1914, on a small tree of *Quercus alba*. This tree was suppressed, and although when cut down it showed about 30 annual rings it was only 16 feet high and about 2 inches in diameter. It was in a moist, shady locality close beside a stream, and in spite of its small size was apparently healthy. The inoculations were made in the usual way from a culture of *E. parasitica* on corn meal. On August 1 it was noted that all four inoculations were producing pycnidia, and in at least one case typical fans had been developed. On October 15 all four cankers had more than half girdled the seedling. No observations were made during the winter, but at the time the leaves had reached half the normal size, in the spring of 1915, the tree was completely girdled. On July 1 this tree presented an appearance closely similar to that of a small chestnut tree girdled by *Endothia parasitica*. All the leaves above the point of inoculation were dead and remained attached to the branches. Below the girdled portion, water sprouts had developed, as has been frequently described for chestnut trees affected with *E. parasitica*. Cultures made from this tree showed the fungus to be typical of *E. parasitica*. Whether this case of parasitism was due to unusual virulence on the part of the fungus or to unusual susceptibility on the part of the host is, of course, merely a matter of conjecture; the latter alternative seems, however, somewhat more probable, as other inoculations with this strain of the fungus on *Q. prinus* and *Q. alba* failed to show similar results.

In addition to the above, a somewhat similar observation has been made by the writers near Amherst, Mass. In connection with other work, a sprout of *Quercus prinus* about an inch in diameter was inoculated with *Endothia gyrosa* on July 15, 1914. When this inoculation was made the tree was partly (about one-fourth) girdled. *E. gyrosa* developed normally and by October 1, 1914, had produced several pycnidial stromata. No change was apparent when the inoculations were examined in May, 1915.

E. parasitica was abundant in the region, however, and apparently gained entrance through the cuts originally made, for when the plat was next visited, August 17, 1915, the sprout appeared quite dead, though still retaining its full-sized dead leaves. Further examination showed numerous pycnidia of *E. parasitica* in addition to those of *E. gyrosa* near the region of the original inoculation. The pycnidia of *E. parasitica* were on all sides of the stem, while those of *E. gyrosa* were confined to the portion above the cuts made in inoculating. The mycelial fans typical of *E. parasitica* were abundant also. These

observations leave no doubt that the tree was girdled and killed by *E. parasitica*.

Endothia parasitica in exceptional cases undoubtedly attacks other hosts than *Castanea*, producing cankers and sometimes causing the death of the host. The results of the inoculations just recorded appear to indicate that some unusual conditions of host or parasite must obtain in such cases. Whether such a combination of conditions or factors will ever become sufficiently frequent to lead to serious destruction of *Quercus* or other forest trees remains to be determined.

ENDOTHIA PARASITICA ON CASTANEA SPP.

Although found occasionally on species of other genera, *Endothia parasitica* is dangerously pathogenic only on members of the genus *Castanea*. The parasitism of this fungus on the American chestnut (*Castanea dentata*) was first proved by Murrill (57) and has since been demonstrated by numerous investigators.

When *Endothia parasitica* was discovered in the United States it was considered by some investigators to be a native fungus which had suddenly become parasitic, and various theories were advanced to account for the supposed unusual susceptibility of the host. As enumerated by Clinton (18, p. 391), the factors suggested include winter injury, drought injury, fire injury, weakened condition due to continued coppicing, and reduced amounts of tannic acid due perhaps to weather conditions.

Continued study by many investigators in different localities has, however, fully confirmed the observation originally made by Metcalf and Collins in 1910 (53) that "a debilitated tree is no more subject to attack than a healthy one" and that *Endothia parasitica* is actively parasitic on the healthiest specimen of *Castanea dentata* in case there is opportunity for wound infection. The writers have personally made over 1,200 inoculations of *E. parasitica* on *Castanea dentata* without finding a single individual that showed any resistance.

CASTANEA ON LIMESTONE SOILS.

Not only are all trees susceptible, but so far as is known no condition of soil, altitude, or moisture renders them more resistant to the disease. The idea has been held by some writers that chestnuts grown on limestone soils were immune to the disease, and the planting of chestnut orchards on such soils was advocated. This view is held by Gulliver (38, p. 53), who sums up his observations in two regions in Pennsylvania as follows:

In every series of tracts taken from limestone to overlying shale soils, the percentage of blight is least at a comparatively short distance * * * from the edge of the limestone. Tracts on soils derived from limestone which show the highest percentage of blight seem to be those where the soil has

become acid from underground drainage. Chestnut trees on soils derived from other alkaline rocks show less blight than is found in the trees on shale soils with limestone underneath.

On the other hand, Detwiler (24, p. 67) reports observations in the Lizard Creek valley which seem to show that these relations do not always occur. He says—

A belt of limestone borders Lizard Creek valley on the south, and the per cent of infection is as high in that region as elsewhere. Infection centers have been found near limestone quarries, where the roots of the chestnut penetrated to bedrock.

Actual proof or disproof of the truth of this idea was peculiarly difficult, since chestnut is but rarely found growing naturally on calcareous soils. During the summer of 1914, however, a careful study of the chestnut on certain portions of limestone areas in western Maryland and western Connecticut was made. These localities were chosen because they were convenient in connection with other work, the blight had been present for several years in both States, and thorough State geological surveys made the location of the limestone areas very easy. The two States also are sufficiently far apart to eliminate sources of error that might arise from local weather conditions.

In western Connecticut chestnut was abundant on glacial till over the Stockbridge limestone of this region. Chestnut was also growing directly over limestone at various points near Danbury, Twin Lakes, Chapinville, and Lakeville. Several localities near the latter place were kindly pointed out by Dr. George E. Nichols. Near Danbury every tree examined showed the blight in a more or less advanced stage, while near the other towns, all in the northwest corner of the State, nearly 50 per cent of the trees were blighted. About 30 inoculations were made on sprouts in this region, and all except two developed cankers quite as rapidly as did check inoculations made on the trap ridge west of Hartford.

Chestnut is very rare on the Shenandoah limestone in the Hagerstown and Frederick valleys of western Maryland. A number of chestnut trees were, however, located growing on limestone soil near Frederick Junction and Adamstown in the Frederick valley. The disease was already established west of Adamstown, where 20 per cent of the chestnuts were either diseased or dead. Twenty-two inoculations were made on nine chestnut sprouts in these two regions, and all developed typical cankers quite as rapidly as the checks made in similar sprouts growing over Baltimore gneiss 50 miles east.

RECESSION OF THE CHESTNUT IN THE SOUTHERN STATES.

While it has been definitely proved that *Endothia parasitica* is pathogenic on healthy chestnut trees, one of the points brought for-

ward by the advocates of the "weakened host" theory seems to be fully established; that is, that the chestnut trees have suffered severely in the southern Appalachian regions previous to the present epidemic, in some cases being practically exterminated, so that the range is now considerably less than formerly. The evidence on this point has been summarized by Clinton (18, pp. 408-413). Various writers quoted by him cite fire injury and borers and other insects as causes for this recession.

Long (48, p. 8) considers a root rot due to *Armillaria mellea* as "very probably an important factor in the gradual recession of the chestnut" in North Carolina. It seems probable that all of the above-mentioned factors, and perhaps others, have played a part in the destruction of the chestnut in this region.

RELATIVE SUSCEPTIBILITY OF SPECIES OF CASTANEA.

The importance of *Castanea dentata* as a timber and nut tree and its abundance in eastern North America, where the blight is prevalent, has made the chestnut blight an object of much investigation. Descriptions of the nature and importance of the disease, the rate of its spread, methods of distribution, and attempted methods of control have been given in detail by Anderson (1-5), Clinton (12-15), Heald (39-41), Metcalf (51 and 52), Metcalf and Collins (53), Rankin (62), and others. It may be sufficient here to state that the fungus enters the host through a wound in the bark, probably never or very rarely through lenticels or natural cracks, grows chiefly in the cambium, penetrating for only short distances into the wood, and kills the tree or branch by girdling. Once a tree is attacked, it is only a question of time till it succumbs.

The chinquapin (*Castanea pumila*) was found by Murrill (58) in 1908 to be attacked by *Endothia parasitica*. Rogers and Gravatt (65) in 1915 made inoculations of *E. parasitica* on *C. pumila* and found that the parasite grew as rapidly on this host as on *C. dentata*. They attribute the apparent resistance of the chinquapin to its comparative freedom from bark injury, a view also held by other writers. Pantanelli (60) and Metcalf (52) have proved that the European chestnut is readily susceptible to the disease.

The only chestnuts thus far observed which show any resistance to *Endothia parasitica* are those of oriental origin. Metcalf (51) first pointed out the resistance of the Japanese chestnut. This observation has since been confirmed by Clinton (18, p. 375), who "failed to produce the disease in a Japanese variety in the [Conn.] station yard, although the bark was inoculated in 16 different places."

Van Fleet (84), in describing the spread of the chestnut blight in his breeding plats at Washington, D. C., says (p. 21): "The Asiatic chestnuts and the chinquapin-Asiatic hybrids are plainly highly resistant."

Morris (56) sums up eight years' observation of the effect of the chestnut blight on 26 species and varieties of chestnuts at Stamford, Conn., as follows:

Every one of the 5,000 American chestnut trees became blighted * * * None of [the grafted varieties or seedlings of European and Asiatic varieties appear] to be as vulnerable as the American chestnut, but most of mine are now dead. Korean chestnuts and chestnuts from the Aomori regions in Japan resisted the blight until six years of age. Since that time they have shown a marked tendency to blight, but resist it better than does the American chestnut * * * None of the American species of chinquapin * * * has blighted with the exception of two limbs * * * None of the specimens of *Castanea alnifolia* [or] * * * of *Castanea mollissima* has blighted, but these latter include only five trees.

These observations as to the resistance of the oriental varieties of chestnut when grown in America are of particular interest in connection with the observations of Meyer in the region where he discovered *Endothia parasitica* native. In his letter to Fairchild, written from Santunying, China, June 4, 1913, Meyer makes the following notes with reference to the effect of the blight in that region:

This blight does not by far do as much damage to Chinese chestnut trees as to the American ones * * *

Not a single tree could be found which had been killed entirely by this disease, although there might have been such trees which had been removed by the ever-active and economic Chinese farmers * * *

Dead limbs, however, were often seen and many a saw wound showed where limbs had been removed * * *

The wounds on the majority of the trees were in the process of healing over * * *

Old wounds are to be observed here and there on ancient trees.

Meyer's photographs taken near Santunying substantiate his statements. Certainly no specimens of *C. dentata* in a blight-infested region in this country could survive to the age of the Chinese chestnuts shown in his photographs.

That the Chinese chestnuts are by no means uniformly resistant, however, is clearly shown by Meyer's later notes. On the label of a package of *Endothia parasitica* collected on chestnut at Tachingko, Shantung, China, March 21, 1914, he writes, "Trees very severely attacked, many dying off," and in a letter written from the same place he says, "A serious canker; many of the trees here were killed by it."

Further evidence that the virulence of *Endothia parasitica* on Chinese chestnut differs in different parts of China is found in subsequent communications from Meyer. From a point near Chingtsai, Chekiang, China, on July 15, 1915, he writes: "All around Hangchow and west of it one finds the chestnut trees seriously attacked by this destructive bark fungus."

On July 11, 1915, near Changhua, Chekiang, China, he comments, "With the exception of near Taianfu, Shantung, chestnuts

are much more severely attacked in the Chekiang Province than either in Chihli, Shansi, or Shensi. Could the greater humidity of central China be of assistance to a more vigorous development of this destructive fungus?"

COMPARISON OF HOST RELATIONS.

It will be seen from the above description of the host relations of the various species that while some other members of the genus (*E. gyrosa*, e. g.) may have slight parasitic tendencies, *Endothia parasitica* alone is an active parasite. The contrast is still more striking in the section of the genus to which *E. parasitica* belongs, for *E. fluens* and *E. fluens mississippiensis*, which resemble *E. parasitica* so closely in their morphological characters, and to a less degree on culture media, and are common on *Castanea*, are almost purely saprophytic. This fact is established by the work of Anderson (2), Clinton (18), and others, and by two years' field observations and several thousand inoculations made by the writers and their colleagues.

The host relations of the parasite are equally striking. Although *Endothia parasitica* is so pathogenic on *Castanea dentata* that this tree has been practically exterminated over several hundred square miles of its natural range and its extinction is threatened, the fungus has been only occasionally found as even a weak parasite on the closely related genus *Quercus*, and never, to the writers' knowledge, on *Fagus*.

During the course of this work the writers have been continually impressed with the possibilities of a physiological study of *E. parasitica* and one or more closely related species which might throw some light on the fundamental question of the nature and cause of parasitism. No other case is known to the writers of a virulently parasitic fungus and a closely related purely saprophytic one which will grow readily and fruit on a large variety of artificial media, which are readily distinguishable on those media, and remain constant for hundreds of generations.

SUMMARY.

The pathological and economic importance of this group of fungi was first recognized when the chestnut-blight fungus was discovered in New York in 1904.

This organism was first referred to the genus *Diaporthe*, but was later shown to belong to the genus *Endothia*.

The specific identity, relationships, and native home of this parasite were at first uncertain. Some pathologists considered it a native organism which was attracting attention and causing injury chiefly

by reason of the weakened condition of the chestnut trees. Others believed it to be of foreign origin. Its recent discovery in China and Japan has settled this question.

To determine positively the identity of the organism, a thorough study was made of the types or authentic specimens of all the species of *Endothia* obtainable. As a result of this work a revision of available species of the genus is presented. This is based upon the field and laboratory study of over 600 collections. Over 4,000 cultures have also been studied.

Endothia gyrosa (Schw.) Fr. is the type of the genus, which is naturally divided into two sections, chiefly by the character of the ascospores. In section 1 they are short, cylindric to allantoid, and continuous or only pseudoseptate. This section contains two species, *E. gyrosa* and *E. singularis*.

Section 2 has oblong-fusiform to oblong-ellipsoid uniseptate ascospores. This contains four species and one variety, *Endothia fluens*, *E. fluens mississippiensis*, *E. longirostris*, *E. tropicalis*, and *E. parasitica*. *E. tropicalis* is a hitherto unrecognized species.

Radiating layers of yellowish or buff mycelium situated in the bark and cambium of the host are found to be constant and distinctive characteristics of *Endothia parasitica*. None of the other species studied shows this character.

All species of the genus possess a stroma having a distinctive yellow to reddish color.

There is no division of stroma into distinct layers, as described by some authors. Pycnidia or perithecia may arise in any portion of the stroma. Most commonly where pycnidia and perithecia are both present the pycnidia are above the perithecia, though the reverse arrangement is sometimes observed and all intermediate conditions frequently occur.

The stromata of the species of section 1 are larger, more erumpent, and contain more numerous pycnidia than those of section 2. *Endothia singularis* is especially striking in this respect. The stromata of section 2 are smaller and very similar in all the species.

The pycnidia consist of more or less irregular chambers or locules in the stroma.

The pycnosporos are small in most species and furnish no very distinctive specific characters. The pycnosporos of *Endothia tropicalis* are, however, constantly larger and more variable in size than those of the other species.

Paraphyses have been described by some authors, but have never been observed by the writers.

The ascospores in the species of section 1 are very similar in size and shape. Those in section 2, though similar, have been found by thorough study and careful measurement to show constant though

slight differences, as indicated in the tables of measurements and ratios.

Numerous cultures of all the species on a variety of media show that each species has constant and distinctive characters of growth and color.

All the species grew equally well in light or darkness, and no decided differences in temperature relations have been demonstrated.

The species appear to have well-defined geographic limits of distribution, which have been approximately determined for the American species. The distribution of the species does not coincide with that of the hosts, but seems to be determined in part by soil and climatic conditions.

Endothia fluens has the widest distribution, being frequent and widely distributed in Europe and the eastern United States, and also occurring in Asia.

Endothia parasitica is evidently of oriental origin. Specimens have been received from five rather widely separated localities in China and from two localities in Japan. In the eastern United States it is now abundant from Maine to North Carolina and is rapidly spreading south and west. It has already destroyed most of the chestnut trees within a radius of 100 miles of New York City.

The species have rather definite host relations.

Endothia gyrosa has been found on five genera of plants, viz, *Castanea*, *Fagus*, *Liquidambar*, *Quercus*, and *Vitis*.

Endothia singularis occurs, so far as known, only on *Quercus* species.

Endothia fluens has been found in America only on *Castanea* and *Quercus*, but in Europe it occurs on *Alnus*, *Carpinus*, *Castanea*, *Corylus*, *Quercus*, and *Ulmus*, and has been reported on *Aesculus*, *Fagus*, and *Juglans*.

Endothia fluens mississippiensis has been found only on *Castanea* and *Quercus*.

Endothia tropicalis is known only on *Elaeocarpus*.

Endothia parasitica has been found on *Acer*, *Carya*, *Castanea*, *Quercus*, and *Rhus*, but at present is only known as a serious parasite on *Castanea*.

Upon the American species of *Castanea* it is actively parasitic under all the conditions of soil and climate observed. Oriental species of chestnut are more or less resistant to the disease both in America and their native homes.

None of the species except *Endothia parasitica* has thus far been found to be actively parasitic.

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PROFESSIONAL PAPER

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THE CONTROL OF DAMPING-OFF OF CONIFEROUS SEEDLINGS.

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THE DISEASE.

Damping-off is a term commonly used to describe the disease causing the death of very young seedlings due to various parasitic fungi. The damping-off of conifers in the United States has been found to be caused by the fungi *Pythium debaryanum* Hesse, *Fusarium moniliforme* Sheldon, and the common American *Rhizoctonia*, usually referred to as *Corticium vagum* B. and C. var. *solani* Burt. Other species of *Fusarium* and other fungi are probably also concerned to a less extent. Most affected seedlings promptly fall over and decay. Those which are not attacked till they are 4 to 8 weeks old may have such wiry stems that they merely turn brown and remain standing after death. This later type of injury is caused by parasites in the same way as the decay of the more succulent younger seedlings, though nurserymen do not always recognize it as the same thing.

ECONOMIC IMPORTANCE OF DAMPING-OFF.

Damping-off has been a handicap to nearly all nurserymen who raise conifers from seed. In most nurseries a large number of seedlings are lost every year. The loss is ordinarily considerably heavier than the nurseryman realizes. Very young seedlings decay and disappear so soon after infection that the number of dead seedlings

visible at any one time is but a small part of the total loss. Furthermore, many of the seedlings are killed immediately after the seed sprouts and before the seedlings appear above the soil surface. Many failures hitherto attributed to poor germination are in reality due to the work of the damping-off parasites in the sprouting seed, underground. The high price of most evergreen seed makes this loss of young seedlings a serious matter.

The cost of seed¹ ranges from a minimum price of 50 cents per pound for western yellow pine (*Pinus ponderosa* Laws.) collected by the United States Forest Service to \$2 to \$4 per pound quoted by commercial seedsmen for the native spruces and \$5 to \$10 per pound for Norway pine (*Pinus resinosa* Ait.). The regular annual loss is, however, not the most serious result of the disease. The most troublesome thing from the commercial standpoint is the great variation in the prevalence of the disease. In some seasons the loss is relatively slight, while in others the seed beds may be almost a total loss. The results of a damping-off epidemic are shown by the poor stand in the untreated plats in Plate I. Such epidemics make it impossible for a nurseryman to secure any regularity in production. The difficulty of controlling damping-off has caused many nurserymen to give up raising their own seedling conifers.

The loss from damping-off can not be figured merely on a basis of the number of the seedlings destroyed. The most serious aspect of the disease is the extent to which planting is discouraged by it. Reforestation of watersheds is one of the great needs of the present time. When interest on the cost of a forest plantation is compounded for the 80 or 100 years which must elapse between forest planting and timber cutting, a very slight initial increase in the cost of planting stock becomes a heavy charge against the ultimate timber value of the plantation, on which the owner must depend for direct returns. It is necessary in order to encourage forest planting to eliminate all possible cost items in the establishment of plantations. Both the average loss and the irregularity in production due to damping-off are reflected in the prices of coniferous planting stock, so that the disease must be controlled to give the maximum opportunity for profitable reforestation. It has previously been possible to import pine stock from Europe cheaply. This has resulted in the introduction of very dangerous insect and fungous pests. The importation of all pines is now prohibited, and the danger of the further introduction of parasites on imported stock of other conifers makes it necessary that the domestic nursery industry be developed on an economic scale that will eliminate all need or incentive for importation. To do this, all important native diseases, of which damping-off is the most serious, must be controlled.

¹ Information furnished by the Office of Forest Investigations, United States Forest Service.

RELATION BETWEEN NURSERY METHODS AND THE CONTROL OF DAMPING-OFF.

A great deal has been written, largely in horticultural journals, on the methods best calculated to prevent damping-off. It has been generally agreed that beds should be well drained and aerated and should have no more water or shade than absolutely necessary. Surfacing beds with gravel, coarse sand, or heated sand has also been recommended. All of these measures have value, but all have their limitations. All of them combined are not sufficient to prevent heavy losses when the damping-off parasites are present in sufficient quantity.

THE BEST SOIL FOR SEED BEDS.

In general, where there is a chance to choose between different seed-bed sites it is safest from the standpoint of damping-off control to select a site with a sandy soil. Either because such soils are better drained or because they contain less organic food matter for fungi, damping-off is commonly less troublesome on light than on heavy soils. A sandy soil is by no means a guaranty of freedom from disease, the heaviest damping-off losses in the writers' experience having occurred on a soil consisting of nearly pure sand. Alkaline soils are believed to favor damping-off. If this is found to be the case, it may explain the fact that some of the heaviest losses from damping-off occur in Nebraska and Kansas rather than in the more humid Eastern States.

Where it is necessary to put seed beds on a soil where damping-off is troublesome, the soil may be improved in various ways. Where sand is easily available, it may pay to haul it in and mix it with the surface soil. Excellent results have been obtained in one case in the writers' experience by making the entire upper 3 inches of the bed of very sandy subsoil just dug up. A less expensive procedure which has also given indication of value is to cover the seed with subsoil taken from a point so far below the surface that it is likely to be free from parasitic fungi and an unfavorable medium for their growth. It is usually better to cover seed with sand than with heavy soil, and surfacing the beds with coarse sand or gravel after the seed is sown and covered is considered helpful. Surfacing the beds after germination with heated sand applied as hot as the hand can stand has also been recommended. Tests by the writers of hot sand on seed beds in a sandy western soil had no perceptible effect on the disease.

AVOIDANCE OF EXCESSIVE MOISTURE.

To secure drainage, seed beds are commonly raised from 2 to 3 inches above the paths, and at some nurseries the surface of the bed is arched to increase run-off. This is probably good practice at most nurseries, but on very sandy soils in a dry climate it does not appear to

have any value whatever. To secure aeration the best eastern nurseries leave their beds entirely open to the wind, or, if side walls are needed to exclude seed-eating animals, they use wire netting only. Yet, at a nursery in western Kansas, after trying the rather expensive netting sides, it was found by forest officers that as good or better results were obtained by using beds with tight board sides. It is well known that excessive moisture and shade must be avoided in the seed beds. However, in sandy soils or in a dry country there is nearly as much danger of getting the beds too dry as of keeping them too wet. Drought often kills large numbers of seedlings in beds left without water.

Aside from common drought injury the effort to keep seed beds dry may result in an entirely different type of trouble. If seed beds are insufficiently shaded and the soil surface is not kept moist, there is at some nurseries serious loss from "white-spot" injury. This injury in seedlings up to 3 weeks of age appears as a whitening and shrinking of the stem just above the ground line. The shrunken area in most cases girdles the stem, the seedling falls over, and death follows. When the injury occurs on one side only it is usually the south or southwest side of the stem that is affected. The symptoms are very much like damping-off, the decided white color of the part of the stem first affected being the most noticeable difference. This white-spot injury is caused not by parasites but apparently by heat, with which possibly may also be combined the direct effects of intense light. The temperature at the surface of a dry, loose soil exposed to the sun may exceed 140° F., a very high temperature for most tender plant tissues to endure for any length of time. White-spot injury is almost always mistaken for damping-off, and has been observed to kill more than half of the seedlings in unshaded beds of even so heat-resistant a species as western yellow pine (*Pinus ponderosa*). In withholding water and shade from coniferous seed beds, nurserymen must be very careful or the loss from drought and white-spot will much exceed the advantage from decreased damping-off loss. Keeping the beds dry is impossible in wet weather and dangerous in dry weather, and it therefore will never be more than a partial control method for damping-off.

FERTILIZERS.

The relation between soil fertilization and damping-off has been but little investigated. In preliminary tests dried blood and nitrate of soda have apparently favored the damping-off parasites, and their use on pine seed beds is considered inadvisable. However, in Vermont¹ tankage has given excellent results against damping-off. It is evident that further tests of nitrogenous fertilizers are needed.

¹ Gifford, C. M. The damping-off of coniferous seedlings. Vt. Agr. Exp. Sta. Bul. 157, p. 170. 1911.

Lime in small quantities has had no appreciable effect, while applications at the rate of 1 ton per acre to beds of jack pine (*Pinus banksiana* Lamb.) in Nebraska have had bad effects. At Burlington, Vt.,¹ wood ashes have been added to seed beds with disastrous results. Lime also caused trouble at Burlington. At Providence, R. I., a mixture of coal and wood ashes tested by Prof. H. H. York seemed to give bad results. Heavy applications of imperfectly rotted horse manure have been known to greatly increase damping-off at the Nebraska nursery, but at the same nursery well-composted manure seems harmless. It is probably safest to manure beds at least a year before seed is to be sown on them. No trouble has been observed to result from the use of green manures, but it may be found that some such crops harbor damping-off parasites and should be avoided. The perennial ragweed of the Southwest (*Ambrosia psilostachya* DC.) serves as a hold-over host for parasitic strains of *Corticium*, so that this and any other weeds known to carry seedling parasites should be eliminated from nursery areas.

DENSITY OF SOWING.

As with truck crops, it is found that pines suffer most from damping-off when sown too closely. A bed containing a stand of seedlings which is too dense will not only lose more seedlings than a less crowded bed, but it will lose a higher percentage of its seedlings. This is due to the ease with which the parasites spread from one seedling to another in dense stands. It has also been found with jack pine that in tests at two nurseries the damping-off loss in seedlings sown broadcast was only four-fifths as great as in adjacent plats sown in drills. In general, beds sown broadcast seem to suffer less from damping-off than beds sown in drills, though with western yellow pine broadcasting has given no better results than the drill method at the nurseries where comparative tests were made.

TIME OF SOWING.

Another item in nursery practice in which variation may affect damping-off is the time at which seed is sown. At some nurseries it makes little difference when seed is sown. In one season beds sown in early spring suffer least from the disease. The next season the latest sown beds may come out the best. However, at some nurseries it is found that there is a best time and a worst time for seed sowing. In a New Mexico nursery it has been demonstrated that July, the local rainy season, is the worst sowing time from the damping-off standpoint. At two western nurseries (in Nebraska and Colorado) the Forest Service has found that yellow-pine seed beds sown in late autumn are comparatively free from damping-off. Repeated tests during two or three successive seasons are necessary

¹ Gifford, C. M. Op. cit.

to determine for any particular nursery whether or not damping-off losses are regularly less in beds sown at a particular time. It is thought that fall sowing is least likely to succeed in localities in which the soil does not remain constantly frozen during the winter.

TESTS OF SOIL DISINFECTION FOR THE CONTROL OF DAMPING-OFF.

The entire matter of the factors controlling the work of the damping-off parasites and the methods of seed-bed management most likely to decrease the disease needs a great deal of further examination. At present adherence to the best known nursery practice will not avoid considerable annual losses at most nurseries or prevent epidemic years in which the beds of certain species are entire failures. The multiplicity of parasites and the different conditions of soil and climate to be met so complicate the problem that it has been found most profitable to make a direct attack on the parasites by the use of disinfectants rather than wait for results by the indirect means of changed nursery management.

Experiments in seed-bed disinfection have been carried on by the writers or in pursuance of their recommendations for the past seven years and at a number of nurseries. At different times assistance has been rendered by Mr. R. D. Rands, Dr. J. V. Hofmann, Dr. T. C. Merrill, Mr. S. C. Bruner, and Mr. G. G. Hahn.

Definite and satisfactory control of the disease has been secured by soil disinfection at every nursery in which extensive experiments have been conducted, and preliminary tests at additional nurseries indicate that while different places require somewhat different procedure, damping-off everywhere can be controlled by proper disinfection of the seed beds. The economic results at all of these nurseries are briefly described in the following pages, together with a summary of the published results of other investigators.

RESULTS OF SOIL DISINFECTION AT NURSERIES WHERE REPEATED TESTS HAVE BEEN MADE.

The first tests were made in pine seed beds in the very sandy soil of the United States Forest Service nursery at Halsey, Nebr. The experience at this nursery was in many ways typical and will therefore be described in some detail.

The first attempt was to control the disease by applying disinfectants after the seedlings appeared above ground. This failed, partly because the disinfectants injured the seedlings and partly because the parasites were found to do a great deal of their work before the seedlings came up. A number of disinfectants were then tested in applications at or before seed sowing. Of these, commercial sulphuric acid appeared the cheapest and most effective. Both heat and formaldehyde, the means usually recommended for disinfecting greenhouse and truck soils, proved less reliable as well as more expensive.

The treatment finally adopted consists of three-sixteenths fluid ounce of sulphuric acid per square foot of seed bed, applied in solution immediately after the seed is sown and covered. The amount of water used to dissolve the acid varies from 1 pint per square foot when the soil is wet to 2 pints when the soil is dry. In all disinfection of seed beds by chemicals the quantity of the disinfectant used per unit area of soil surface seems to be the important variable. The disinfectant must be dissolved in sufficient water to permit its distribution through the soil to a depth of several inches, but within certain limits the concentration of the solution as applied does not appear to be an important factor. The adherence of some investigators to the concentration of the solution used as a measure of soil treatment makes their work difficult to correlate.

In the earlier tests of acid at Halsey chemical injury to the pines occurred in beds treated with acid at the time of sowing. It was found that dormant pine seeds were not injured by acid, but that the root tips of the seedlings in acid beds were often killed just after germination commenced. The way in which this injury occurred made it evident that it was due to the concentration of the acid in the surface soil. Evaporation of water from the soil surface seemed to bring up the disinfectant from the lower soil, just as alkali salts come to the surface in alkali soils. Watering the beds frequently during the germinating period prevents such surface concentration and in practice has been found entirely to prevent injury to the seedlings. The method of protecting the seedlings from acid injury at this nursery is to water the seed beds frequently from the time seed is sown until a few days after germination, when the root tips have penetrated one-half inch into the soil. After this time they are practically safe from further injury. The beds are watered daily in ordinary spring weather, every other day in misty or rainy weather, and twice daily when the maximum temperature exceeds 80° F. In clear weather each watering is at the rate of approximately 1½ pints per square foot of bed. In cold, cloudy weather 1 pint per square foot is found sufficient. (Two-tenths inch of rainfall is equivalent to 1 pint per square foot.)

The acid treatment was repeatedly tested on different species of pine during different years and at different times of the year. In all cases it resulted in increased stands. The results of all the acid tests in which the above watering system or its equivalent was followed are given in Table I.

In addition to the three species given in this table, a test on a series of plats of Corsican pine (*Pinus laricio* Poir.) gave excellent results; an accident prevented the securing of exact figures. Some of the tests included in the table were conducted on a considerable scale, the total area involved being 8,350 square feet in the treated

plats and 547 feet in the untreated plats. In the case of the larger plats, counts of seedlings were made only on sample areas scattered through the plats. The percentages of germination and of death are based on counts of all seedlings on 246 square feet in the treated plats and 145 square feet in the untreated plats. The surviving seedlings were counted on these sample areas and also on additional areas, totaling 406 square feet for the acid plats and 196 square feet for the untreated plats. Damping-off is so variable that only repeated and extensive tests of this sort are entirely reliable.

TABLE I.—*Control of damping-off of pines by three-sixteenths fluid ounce of sulphuric acid per square foot of seed bed applied at sowing time, Halsey, Nebr.*

Species.	Number of separate tests.	Treatment.	Absolute results.			Relative results.		
			Germination. ¹	Death per hundred seedlings. ²	Final stand based on seedsown.	Germination.	Death.	Final stand.
			<i>Per cent.</i>		<i>Per cent.</i>			
<i>Pinus banksiana</i> ³	11	Acid.....	32.7	15.2	26.4	161	35	267
		None.....	20.3	43.7	9.9	100	100	100
<i>P. ponderosa</i>	3	Acid.....	66.3	12.0	58.7	132	33	178
		None.....	59.3	36.7	33.0	100	190	100
<i>P. resinosa</i>	3	Acid.....	70.0	38.7	40.7	112	53	254
		None.....	62.7	73.7	16.0	100	100	100
Average ³	17	Acid.....	56.3	22.0	41.9	135	43	233
		None.....	44.4	51.4	16.3	100	100	100

¹ The germination percentage takes into account only seedlings which appear above the soil. Seeds which started to germinate but did not reach the point of breaking through the soil are not included.

² The death percentage includes all seedlings which died from damping-off and also any which may have died from drought or chemical injury after the seedlings came up. Seedlings broken by hail or other mechanical means or killed by insects are not included.

³ Germination and death figures obtained from only 9 of the 11 jack-pine tests.

The acid in practically all cases caused a marked increase in the number of seedlings that came up, as well as a decrease in the death rate after coming up. Damping-off was not entirely controlled. There was still a loss of 22 per cent after germination in the treated plats, but the loss in the untreated plats was nearly two and one-half times as great. The combined effect of increased germination and decreased death rate was a large increase in the number of healthy seedlings produced. (See Table I, columns headed "Final stand.")

It is especially to be noted that in jack pine and Norway pine, the species with which the most extensive tests were made, more than 250 healthy seedlings were obtained in the treated plats for every 100 obtained from equal quantities of seed in the untreated plats. The results of the acid treatment of Norway pine are strikingly shown by the difference in stand in the treated and untreated plats shown in Plate I, figure 1.

Since the foregoing tests were conducted, the acid treatment has been put into regular use on all spring-sown beds at this nursery and the success of the treatment further confirmed by the continued good results secured.

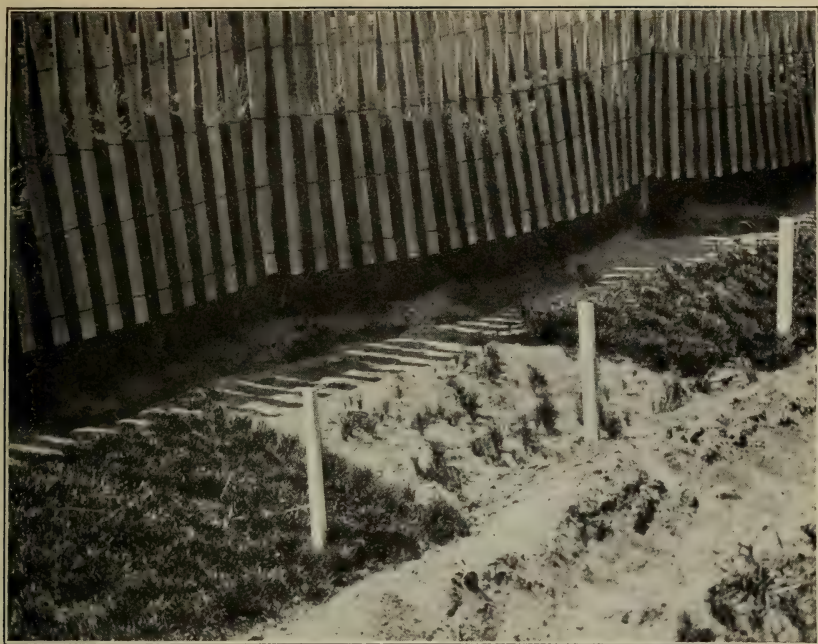


FIG. 1.—NORWAY-PINE SEED BED, 1 YEAR OLD, HALSEY, NEBR.

Plat in center untreated. Remainder of bed treated at time of sowing with a solution containing three-sixteenths fluid ounce of sulphuric acid per square foot of bed. Practically all of the seedlings in the untreated plat have been destroyed by damping-off. Photographed by Charles B. Pool (F 1).

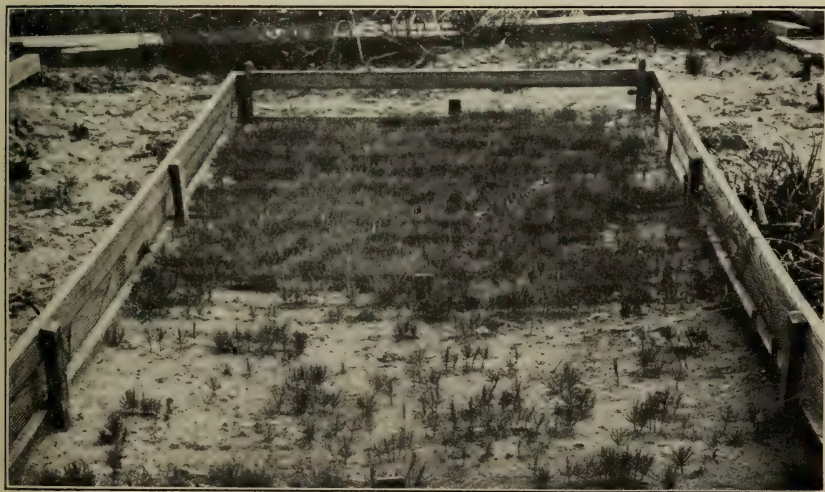


FIG. 2.—WESTERN YELLOW-PINE SEED BED, KANSAS SANDHILLS.

Foreground untreated. Background treated at time of sowing with a sulphuric-acid solution. Most of the seedlings in the untreated plat have been destroyed by damping-off. Photographed by Dr. J. V. Hofmann (F 2).

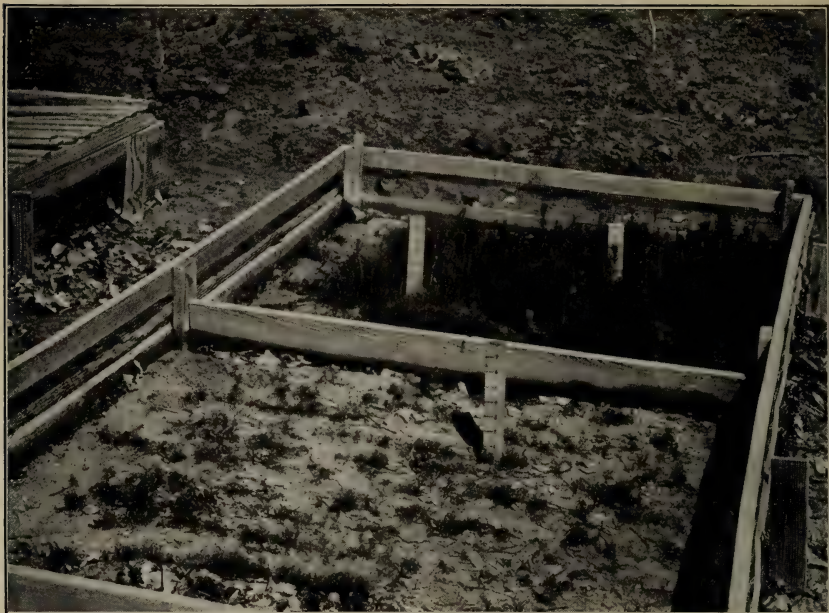


FIG. 1.—JACK-PINE SEED BED, GARDEN CITY, KANS.

Foreground untreated. Background treated with sulphuric-acid solution before germination. Stakes marked in inches. Note the difference in height of the seedlings after the first season's growth (F 3).

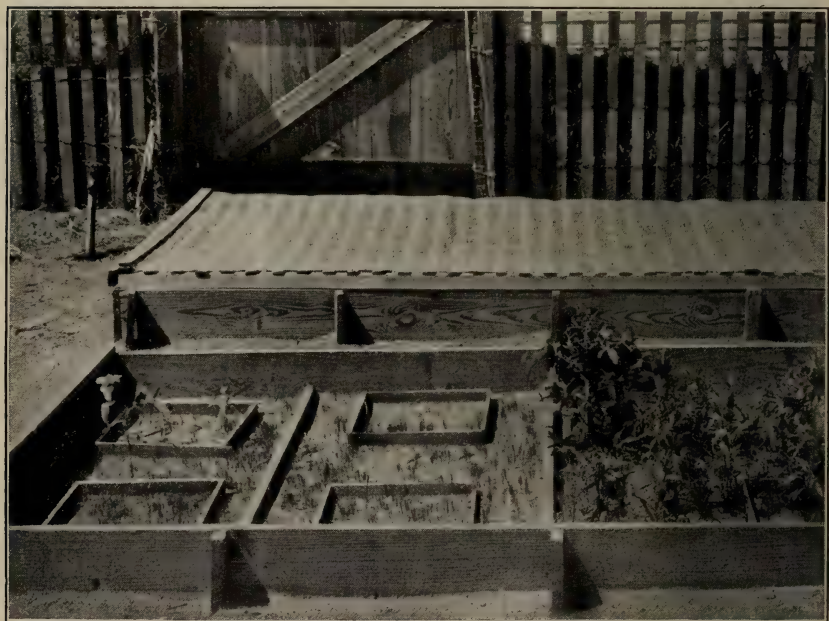


FIG. 2.—JACK-PINE SEED BED, KANSAS SANDHILLS.

Plat at left treated with one-fourth ounce and plat at center with three-eighths ounce of sulphuric acid per square foot. Plat at right untreated. Note the relative freedom from weeds in the treated plats. The apparently thin stand of trees in the treated plats is due to the very small size of the young seedlings of this species of pine. Actual counts in these plats showed the stand to be as dense as can be grown without subsequent overcrowding. Photographed by Stephen C. Bruner (F 4).

At nearly all of the other nurseries sulphuric acid was also found successful in controlling damping-off. However, because of differences in soil and climate, the treatments required elsewhere differed in some details from that at Halsey. On a still lighter sand in Kansas sand hills, which was probably also somewhat more alkaline, it was found that damping-off could be controlled best by a heavier treatment of acid—one-fourth fluid ounce per square foot in ordinary spring-sown beds, and five-sixteenths or three-eighths ounce in beds sown in the fall or very early spring. The watering required during the germinating period to prevent injury to the pines was less than at Halsey. The losses in untreated beds at this nursery were exceptionally heavy. In the treated beds it was not possible to reduce the damping-off loss to as low a figure as at Halsey, probably because of the common occurrence of *Fusarium moniliforme*, a fungus exceptionally able to quickly reinfect treated beds. The success of the treatment from the economic standpoint, however, was greater than at Halsey. Without the treatment, failure occurred in the seed beds more often than success, and stock could not be raised at a reasonable expense. With the treatment, success was the rule, and the economical production of stock became possible. The difference in stand between treated and untreated plats at this nursery is shown in Plate I, figure 2.

At a single nursery on a fine sandy soil near Morrisville, Pa., it was found that it was more difficult than at Halsey to prevent acid injury to germinating seedlings. This was a nursery at which tests were made during a single season only. It is mentioned at this point merely to show the difference in behavior of acid in different soils. Even one-twelfth fluid ounce per square foot caused injury to the pines at Morrisville. Indications from the small series of tests conducted there were that one-eighth ounce of acid per square foot would probably prove effective against damping-off and harmless to coniferous seedlings if followed by sufficiently frequent watering during the germinating period. It is likely that this soil was slightly acid to start with.

In marked contrast to the experience at Morrisville are the results obtained at Fort Bayard, N. Mex., Monument, Colo., and Haugan, Mont. At all of these places acid at the rate of three-sixteenths ounce or more per square foot has been applied to the beds at sowing in repeated tests, without any injury to the seedlings that could be detected by the forest officers in charge at the nurseries. At Fort Bayard Mr. H. C. Turner has tested the acid very thoroughly for four successive seasons and in quantities up to five-eighths ounce per square foot without finding any injury to seedlings. Even three-sixteenths ounce proved reasonably efficient in decreasing damping-off, and the five-eighths ounce treatment reduced the loss to less than 1 per cent.

At Haugan the acid has been used for three years and damping-off has been practically abolished in the beds treated. These three nurseries differ from the preceding three in that the soil is heavier and there is no need of any extra watering in order to prevent chemical injury to the seedlings.

At a seventh nursery an entirely different condition was encountered. The seed beds were located on a rather heavy soil near Garden City, Kans. This soil effervesced vigorously when treated with acid, yielding 0.23 per cent of carbon dioxid from the surface soil and over 1 per cent from the subsoil in a test made by the Bureau of Soils. Acid treatments had no effect on damping-off in this soil, owing presumably to the high carbonate content and consequent alkalinity which the effervescence indicated. Tests with copper sulphate, one-fourth ounce per square foot, and zinc chlorid, one-half ounce per square foot, showed that both these and heavier treatments were effective against damping-off. The results are given in Table II.

TABLE II.—Control of damping-off of pines by one-fourth to three-fourths ounce copper sulphate and one-half to one ounce zinc chlorid per square foot of seed bed, Garden City, Kans.

Species and time of sowing.	Disinfectant.	Number of separate tests.	Absolute results.			Relative results.		
			Germination.	Death per hundred seedlings.	Final stand based on seed sown.	Germination.	Death.	Final stand.
<i>Pinus austriaca</i> :			<i>Per ct.</i>		<i>Per ct.</i>			
Spring.....	Copper sulphate.....	2	{ 40.1	59.0	21.3	254	65	1,638
	None.....		{ 15.8	91.0	1.3	100	100	100
	Zinc chlorid.....	1	{ 37.5	99.0	.5	192	99	(a)
	None.....		{ 19.5	100.0	0	100	100	(a)
<i>P. banksiana</i> :								
Fall.....	Copper sulphate.....	3	{ 27.1	35.2	16.1	105	56	212
	None.....		{ 25.9	62.3	7.6	100	100	100
	Zinc chlorid.....	3	{ 30.7	27.6	21.0	130	40	362
	None.....		{ 23.7	69.0	5.8	100	100	100
Spring.....	Copper sulphate.....	2	{ 16.6	67.8	9.0	143	101	143
	None.....		{ 11.6	67.0	6.3	100	100	100
	Zinc chlorid.....	2	{ 37.5	20.0	28.9	264	30	452
	None.....		{ 14.2	66.0	6.4	100	100	100
Average, fall and spring..	Copper sulphate and zinc chlorid.	.....	28.0	37.7	18.8	148	57	289
	None.....	.....	18.9	66.1	6.5	100	100	100
<i>P. ponderosa</i> :								
Fall.....	Copper sulphate.....	2	{ 46.1	20.1	34.8	113	34	217
	None.....		{ 40.9	59.8	16.0	100	100	100
	Zinc chlorid.....	2	{ 42.9	16.1	33.1	117	28	183
	None.....		{ 36.6	57.4	18.1	100	100	100
Spring.....	Copper sulphate.....	8	{ 58.1	24.0	42.2	114	53	147
	None.....		{ 50.9	45.1	28.7	100	100	100
	Zinc chlorid.....	6	{ 61.3	b 11.8	46.6	116	30	150
	None.....		{ 52.7	b 39.1	31.0	100	100	100
Average, fall and spring..	Zinc chlorid and copper sulphate.	.....	52.1	18.0	39.2	115	36	167
	None.....	.....	45.3	50.4	23.5	100	100	100

a No expression possible. b The damping-off percentage was determined in but five of the six tests.

Copper sulphate could probably have been used with success in quantities less than one-fourth ounce per square foot. A three-eighths ounce zinc-chlorid treatment proved unsuccessful. Both disinfectants were dissolved in water and applied in most cases just after seed sowing, as was done with acid. Both were found harmless to the dormant seed in these concentrations, but both were capable of injuring germinating seedlings in just the same way as is described for acid at Halsey. This injury was prevented by extra watering during the germinating period, in the same way as acid injury was prevented at the Halsey and Kansas sand-hill nurseries. The amount of this extra watering needed at the Garden City nursery was very slight.

An interesting thing that developed at this nursery, as well as at the Kansas sand-hill nursery, was the control of spring damping-off by treatments applied during November of the preceding year. Part of the fall-sown plats whose results were shown in Table II were treated at the time of sowing and part as soon as the soil thawed the following spring. Though the seedlings did not appear until the following April, disinfectants applied in November seemed to protect them from damping-off as well, or practically as well, as disinfectants applied in March. At this nursery and at the five preceding at which repeated tests were made, the treatments developed have been put into regular large-scale use by the nurserymen, with good results.

RESULTS OF SOIL DISINFECTION AT NURSERIES WHERE TESTS HAVE BEEN LIMITED TO A SINGLE SEASON.

At Porvenir, N. Mex., Dundee, Ill., Lincoln, Nebr., the nursery of the State Board of Forestry in Vilas County, Wis., and the greenhouses of the United States Department of Agriculture at Washington, D. C., single-season tests of sulphuric acid have given good results. At all of these places no need was found for any special watering provision for the prevention of chemical injury from the acid. The tests at Dundee and Lincoln were made during an unusually rainy season. It may develop that in years with less rain more watering will be needed at these places.

At four other nurseries where disinfectants were tested in this preliminary way the results were less definite. At Morrisville, Pa., already referred to, there was distinct evidence that a very weak acid treatment with sufficient watering during the germinating period will be entirely successful in controlling the small amount of damping-off which normally occurs there. One-eighth ounce of acid per square foot it is thought will be sufficient. Insufficient watering prevented the securing of exact information from the tests conducted. At Pocatello, Idaho, a single test of acid on beds of Douglas fir had no conspicuous effect on the amount of damping-off. As the soil is found to effervesce on the addition of acid, success with acid does not

appear probable. At Cass Lake, Minn., acid was tested on seed beds of Norway pine (*Pinus resinosa*) during a period of weather so abnormally cold and wet that the seed lay in the ground for a number of weeks before germination was completed. Under these conditions, for the first time in the writers' experience, the acid treatment of the beds at the time of sowing resulted in decreased germination. No special watering was needed to prevent injury to the tips after the seedlings began to come up; in fact, very frequent watering given one bed resulted in less germination and therefore poorer results than in acid beds with no extra watering. Despite the decrease in germination, the acid beds, because of the almost complete control of damping-off by the treatment, finished the season with an average of 135 seedlings for every 100 in the untreated plats, and the acid plats which were not given excessive water had 151 seedlings for every 100 in the untreated plats. This fact and the fact that acid beds which had first been treated with lime and were thereby kept from injury to the seed produced 228 seedlings for every 100 in the untreated plats indicate that in ordinary seasons the treatment with acid alone will be entirely successful. The use of lime with acid is usually undesirable because by neutralizing the acid it permits the parasites to resume work soon after treatment. Formaldehyde gave better results than acid at Cass Lake. While it is thought that this would not be the case in a normal season, it is evident that further tests are needed to determine what treatment to use.

The danger in drawing conclusions from the results of three or four test plats is shown especially well by the results obtained by Prof. H. H. York, of Brown University, in testing treatments recommended by the writers. Treatments involving five-sixteenths ounce of sulphuric acid, five-eighth ounce of zinc chlorid, and $2\frac{1}{2}$ ounces of cane sugar, respectively, per square foot of bed, resulted in final stands from $4\frac{1}{2}$ to 15 times as dense as in most of the untreated plats. One untreated plat, however, gave a stand as dense as that on the treated plats. This throws doubt on the reliability of the results on the other plats and indicates that only repeated tests, each with plenty of untreated plats for abundant comparison, are reliable enough to be used as a basis for conclusions.

At several of the nurseries mentioned above other soil treatments were tried with success. At Glenview, Ill., where acid failed, copper-sulphate treatment resulted in doubling the final stand. The good results obtained on otherwise untreated soil at Dundee, Ill., by the addition of cane sugar were rather surprising; indications of damping-off control by sugar were also observed at Garden City, Kans., East Tawas, Mich., and Providence, R. I. Further tests are required. At East Tawas, a test of acid in an unfavorable season did not give as good results as desired, while formaldehyde resulted in a doubled stand.

RESULTS OF SOIL DISINFECTION IN GREENHOUSE TESTS.

In the greenhouses of the Department of Agriculture at Washington, D. C., disinfection of soil by steam pressure has proved reasonably effective in controlling damping-off of pine seedlings in most of a rather large number of tests conducted during the winter months. During the summer there is so much reinfection that the results of heat disinfection are uncertain. A single test of sulphuric acid in the spring of 1915 indicated the value of acid treatment in reducing damping-off in the greenhouse. Four flats of jack pine were treated with sulphuric acid in quantities of three-sixteenths to three-eighths ounce per square foot just after sowing. The relative survival in the acid flats, taking the average survival in the untreated flats as 100, was 128. The relative survival in flats disinfected by steam was only 105. Three-sixteenths ounce of acid per square foot gave as good results as heavier treatments. The soil used in this experiment was a mixture of seven parts loam, four parts sand, two parts manure, and one part leaf mold.

RESULTS IN DISINFECTING THE SOIL OBTAINED BY OTHER INVESTIGATORS.

Spaulding,¹ who appears to have been the originator of the use of sulphuric acid for soil disinfection, has tested acid and other disinfectants at several places. In greenhouse tests formaldehyde and copper sulphate were found valuable, but the sulphate injured seedlings. At Saranac Inn, N. Y., formaldehyde apparently increased damping-off one season and controlled it in a later season, while sulphuric acid injured seedlings and gave results which from the economic standpoint were inconclusive.

At Burlington, Vt., results with disinfectants in pine-seed beds have been reported by Spaulding,² Jones,³ Gifford,⁴ and Burns.⁵ Formaldehyde applied five days before sowing and allowed to evaporate for two days before sowing killed part of the seed. All of the writers found formaldehyde of decided value in controlling damping-off. Jones and Spaulding report a single test in which but one-tenth ounce (0.106 ounce) of formaldehyde was used per square foot and excellent results obtained. The subsequent tests reported have been with amounts of 0.48 ounce or over per square foot. The treatment used by Burns, of 0.58 ounce of formaldehyde per square foot, applied

¹ Spaulding, Perley. The damping-off of coniferous seedlings. *In* Phytopathology, v. 4, no. 2, p. 73-88, 2 fig., pl. 6. 1914.

——— The treatment of damping-off in coniferous seedlings. U. S. Dept. Agr., Bur. Plant Indus. Circ. 4, 8 p. 1908.

² Spaulding, Perley, 1914. Op. cit.

³ Jones, L. R. The damping-off of coniferous seedlings. *In* Vt. Agr. Exp. Sta. 20th Ann. Rpt., 1906-7, p. 342-347. 1908.

⁴ Gifford, C. M. The damping-off of coniferous seedlings. Vt. Agr. Exp. Sta. Bul. 157, p. 141-171, 10 fig., 4 pl. 1911.

⁵ Burns, G. P. Studies in tolerance of New England forest trees. I. Development of white pine seedlings in nursery beds. Vt. Agr. Exp. Sta. Bul. 178, p. 125-144, 2 fig., 4 pl. 1914.

11 days before sowing, with the beds tightly covered during the interim, appears to have been entirely harmless and very effective against the disease. Burns found the sulphuric-acid treatment used by the writers at Halsey, three-sixteenths ounce per square foot applied at time of sowing, as effective as the formaldehyde and non-injurious. Spaulding,¹ reporting tests made in 1907 and 1908, also obtained excellent results with acid, which was not tested by Jones and Gifford. He in addition obtained good results in preliminary tests with copper sulphate and with sulphur.

Acid was also used at an unnamed locality by Güssow,² with excellent results.

Charcoal, an amendment rather than a disinfectant, is reported by Retan³ to be of value against damping-off in the clay soil at Mont Alto, Pa., and to result in the increased size of pine seedlings. A layer 3 inches deep was spaded into the soil. Annual treatment with this amount would, of course, be impracticable. However, Retan states that the effect of such charcoal addition is permanent. Further experience seems necessary to confirm the permanent value of charcoal for preventing damping-off on this and other soils. A single test by the writers of a lighter application of charcoal at the Cass Lake nursery proved unsuccessful.

SOIL-DISINFECTION TESTS SUMMARIZED.

The writers' experience with soil disinfectants at the different nurseries, as well as the experience of other experimenters, has been so varied that it is rather difficult to correlate the results. Correlation will be made easier by reference to Table III, in which are summed up all of the successful tests of treatments of coniferous seed beds of which the writers have been able to learn. In the tests at Halsey, the Kansas sand hills, Garden City, Lincoln, Cass Lake, Dundee, Glenview, and East Tawas, the experimental treatments were applied by the writers or their assistants, with the cooperation of those in charge of the nurseries. At Fort Bayard the tests were conducted by Mr. H. C. Turner, at Monument by Mr. W. H. Schrader, at Porvenir by Mr. H. D. Burrall, at Pocatello by Mr. Arthur P. Say, in Vilas County, Wis., by Mr. W. D. Barnard, at Providence by Prof. H. H. York, at Morrisville under the direction of Mr. John Foley, and at Haugan by forest officers, following recommendations made by the writers.

¹ Spaulding, Perley, 1914. Op. cit.

² Güssow, H. T. Diseases of forest trees. In Com. Conserv. Canada, Rpt. 1st Ann. Meeting, 1910, p. 136-137. 1910.

³ Retan, G. A. Charcoal as a means of solving some nursery problems. In Forestry Quart., v. 13, no. 1, p. 25-30. 1915.

TABLE III.—*Tests of soil treatments for the control of damping-off of conifers.*

AT PLACES WHERE REPEATED TESTS HAVE BEEN MADE.

Locality, soil type, and species used.	Successful treatments.					Important treatments which indicated—			Remarks.
	Treatment.		Number of independent tests.	Resulting stand. ¹	Amount per square foot indicated as best.	Extra watering needed. ²	Less value.	No value.	
	Substance added.	Amount used per square foot.							
1	2	3	4	5	6	7	8	9	10
Halsey, Nebr.; fine sand: Pines, 3 species.....	Sulphuric acid..	Ounces. $\frac{1}{16}$	17	233	Ounces. $\frac{1}{16}$	Yes.....	Formaldehyde, copper sulphate, and heat.		Preliminary tests indicate value for zinc chlorid; degree of value not determined.
Kansas sand hills; fine sand: Pines, 4 species.....	do.....	$\frac{1}{4}$ to $\frac{3}{8}$	14	316	$\frac{1}{4}$ to $\frac{5}{8}$	Yes.....	Formaldehyde and heat.		Preliminary tests indicate value for copper sulphate and zinc chlorid.
Garden City, Kans.; fine sandy loam, with high carbonate content: Pines, 3 species.....	{Copper sulphate. Zinc chlorid.....	$\frac{1}{4}$ to $\frac{3}{8}$ $\frac{1}{2}$ to 1	17 14	229 214	$\frac{1}{4}$ to $\frac{5}{8}$ $\frac{1}{2}$	Yes..... Yes.....	do.....	Sulphuric acid.....	
Fort Bayard, N. Mex.; heavy loam: Western yellow pine.....	{Sulphuric acid.. Zinc chlorid.....	$\frac{1}{16}$ to $\frac{3}{8}$ $\frac{1}{8}$ to $\frac{3}{8}$	10 4	143 149	$\frac{1}{4}$ to $\frac{5}{8}$ $\frac{1}{2}$	No..... (³).....	Formaldehyde.....		Copper sulphate tested with good results; exact value not determined.
Monument, Colo.; loam: Western yellow pine, Douglas fir, Engelmann spruce. Hangan, Mont.; loam: Western yellow pine.....	Sulphuric acid.. do.....	$\frac{1}{16}$ $\frac{1}{16}$	5 3 years.	177 (⁴)	$\frac{1}{4}$ to $\frac{1}{2}$ $\frac{1}{4}$	No..... (³).....			No counts; disease control reported practically perfect.
Burlington, Vt.: Pines, 3 species.....	{Formaldehyde.. Sulphuric acid.. Tankage.....	$\frac{1}{16}$ to 1 $\frac{1}{16}$ to $\frac{1}{8}$ $\frac{1}{16}$	{Results of other investigators.		{ $\frac{1}{4}$ to $\frac{3}{8}$ $\frac{1}{16}$ to $\frac{1}{8}$ $\frac{1}{16}$	No..... (³) (³)	Heat.....		Tankage excellent in single test; preliminary tests indicate value for copper sulphate.

¹ Number in treated plats for each 100 in untreated.² To prevent chemical injury.³ Probably not.⁴ See under "Remarks."

TABLE III.—*Tests of soil treatments for the control of damping-off of conifers*—Continued.

AT PLACES WHERE TESTS HAVE BEEN LIMITED TO A SINGLE SEASON.

Locality, soil type, and species used.	Successful treatments.					Important treatments which indicated—			Remarks.
	Treatment.		Number of independent tests.	Resulting stand. ¹	Amount per square foot indicated as best.	Extra watering needed. ²	Less value.	No value.	
	Substance added.	Amount used per square foot.							
1	2	3	4	5	6	7	8	9	10
Porvenir, N. Mex.; sandy loam:									
Engelmann spruce.....	Sulphuric acid..	Ounces, $\frac{1}{16}$ to $\frac{1}{8}$	2	168	Ounces, $\frac{1}{16}$ to $\frac{1}{8}$	(³).....	Zinc chlorid.....	Formaldehyde and copper sulphate.	Soil contains carbonates.
Pocatello, Idaho; loam:								Sulphuric acid.....	
Douglas fir.....									
Lincoln, Nebr.; very sandy loam:									
Norway spruce, blue spruce, and western yellow pine.	Sulphuric acid..	$\frac{1}{16}$ to $\frac{1}{8}$	2	130	$\frac{1}{16}$	(³).....	Zinc chlorid.....		
Cass Lake, Minn.; sand:									
Norway pine.....	Sulphuric acid..	$\frac{1}{16}$ to $\frac{1}{8}$	4	135	$\frac{1}{16}$ to $\frac{1}{8}$	(³).....	Heat, zinc chlorid, copper sulphate, and charcoal (light treatment).	Sulphur.....	{ For explanation of low figure for acid treatment, see p. 12.
	Formaldehyde..	$\frac{1}{16}$ to $\frac{1}{8}$	1	240	$\frac{1}{16}$ to $\frac{1}{8}$	No.....			
	Air-slaked lime..	$\frac{1}{16}$ to $\frac{1}{8}$	1	228	$\frac{1}{16}$	No.....			
	Followed by sulphuric acid.	$\frac{1}{16}$ to $\frac{1}{8}$							
Vilas County, Wis.; fine sand:									
Pine.....	Sulphuric acid..	$\frac{1}{16}$	1	147	$\frac{1}{16}$	(⁴).....			

Dundee, Ill.; loam (mostly treated with marl):	1 to 3 to 1	4	140 145	(3)..... (3).....	Zinc chloride (when used alone).	Formaldehyde (when used alone), cane sugar (on marled soil).	Zinc chlorid following formaldehyde was dissolved in only three-fourths pint of water per square foot of bed.
Austrian pine.....	2 to 3	2	177	No.....			
		1	181	No.....			
Glenview, Ill.; sandy loam: Douglas fir, hemlock....	1 to 1	2	201	(3).....		Sulphuric acid and zinc chlorid.	
East Tawas, Mich.; fine sand: Norway pine and white pine.	3 to 3	2	200	1 to 1	Sulphuric acid		
Providence, R. I.; sandy loam:	1 to 1	1	(4)	Yes.....			Value indicated, especially for acid and zinc chlorid; extent not determined.
Norway pine.....	1 to 1	1	(4)	Yes.....	Formaldehyde		
Morrisville, Pa.; fine sandy loam:	1 to 1	1	(4)	No.....			Value indicated; extent not determined.
Phies and Norway spruce		1	(4)	Yes.....			
Greenhouse, Washington, D. C.; sandy loam: Jack pine.....	1 to 1	1	128	1 to 1	Heat.....		Results of Spaulding.
Greenhouse, St. Louis, Mo.	1 to 1			No.....			Do.
				Yes.....			Results of Güssow: effect described as excellent.
Saranac Inn, N. Y., sandy				Yes.....			Results of Retani: damping-off apparently decreased.
Canada.....				No.....			
Mont Alto, Pa.; clay	Layer 3 inches thick.						

¹ Number in treated plats for each 100 in untreated.² To prevent chemical injury.³ Probably not.⁴ See under "Remarks."

In most of the treatments listed in Table III the substance used was applied just after the seed was sown and covered. Formaldehyde kills some of the seed if so used and was accordingly applied several days before seed sowing. Either the soil was treated a week or more before sowing in the formaldehyde plats and kept covered with heavy paper for a few days after treatment, or else the treatment was made but two or three days before sowing and no paper was used. Even with these precautions part of the seed was killed in the tests at Burlington, the Kansas sand hills, and Glenview. Zinc chlorid killed the dormant jack-pine seed in two heavily treated plats at Garden City which were sown and treated in the fall and remained dormant throughout the winter. It ordinarily produces no such effect. Sulphuric acid has also shown a tendency to decrease the germination percentage in two or three tests of fall treatments, but ordinarily has no such effect in spring-sown beds. It has never had more than a slight delaying effect on germination except during very wet, cold weather, and its harmful effect on dormant seed in spring-sown beds is negligible. Copper sulphate shows even less tendency than sulphuric acid to injure dormant seed. Sulphuric acid, copper sulphate, and zinc chlorid are all inclined in some soils to injure the root tips of seedlings just after germination begins; on such soils the injury to seedlings can be prevented by very frequent watering during the germinating period. Column 7 of Table III indicates for the best strength of each successful treatment whether or not such extra watering is required. It will be noted that in formaldehyde beds extra watering is nowhere necessary. For the other three disinfectants it is more commonly necessary on very light sandy soils than on heavy soils.

Air-slaked lime, powdered sulphur, and charcoal were applied dry, and in the tests reported by the writers were raked into the upper 3 inches of soil. Copper sulphate was applied in the form of dry powder in the tests reported by Spaulding.¹ Sulphuric acid, formaldehyde, zinc chlorid, and in the tests reported by the writers copper sulphate were applied in solution. The strength of all treatments is expressed in the number of ounces of substance per square foot of bed. For sulphuric acid and formaldehyde the fluid ounce (29.574 c. c.) is the unit of measure, while for all other substances the avoirdupois ounce (28.35 gm.) was used. Three-fourths of an ounce per square foot is practically equivalent to 1 ton per acre. The amount of water used in dissolving the disinfectants varies from 1 to 2½ pints per square foot. For a soil already wet 1 pint is sufficient; for a dry fine-textured soil 2½ pints may be needed to secure a proper distribution of the disinfectant. Ordinarily, 1½ or 1¾ pints per square foot are satisfactory.

¹ Spaulding, Perley. The treatment of damping-off in coniferous seedlings. U. S. Dept. Agr., Bur. Plant Indus. Circ. 4, 8 p. 1908.

COST OF DISINFECTANT TREATMENTS.

Because of the differences between the nurseries where tests have been made, both in the details of the treatment used and in the scale of the operations and the equipment of the nursery in such matters as water supply, it is impossible to make any statement as to the exact costs of treatment.

At two of the nurseries (Fort Bayard, N. Mex., and Haugan, Mont.) mentioned in the foregoing pages, at which the treatments have been in use long enough to permit a definite statement, all that is needed is an application of acid solution to the beds just after sowing. The treated beds thereafter require no more attention than do those untreated. At six other nurseries, where the acid has been in use for a less time, the same appears to be true, while for a seventh nursery, where copper sulphate gives the best results, the same simple method of application appears satisfactory. For these nine nurseries, then, the treatment which has so far appeared most effective involves no expense except that of the single disinfectant application. Different amounts of disinfectant are required for different soils, and because of the rather high cost of transporting sulphuric acid the price of that disinfectant varies greatly in different localities, so that exact costs of the treatment can not be given. It is very evident, however, that both the sulphuric-acid and the copper-sulphate treatments applied in this way are decidedly cheaper than either the formaldehyde or heat disinfection methods as used in out-of-door seed beds of tobacco and other truck crops. At many railroad centers sulphuric acid can be obtained in carboy lots for $2\frac{1}{2}$ cents per pound ¹ or even less, while copper sulphate should not ordinarily exceed 8 cents per pound.¹ With copper sulphate one-fourth avoirdupois ounce and sulphuric acid one-fourth fluid ounce per square foot will be sufficient or more than sufficient at most nurseries. Judging from the experience of truck-crop experimenters and from the results of the writers and others with formaldehyde at several nurseries, one-fourth to one-half fluid ounce per square foot of the more expensive formaldehyde will be needed on most soils to secure sufficient disinfection. If it develops that it is necessary to use the tight cover prescribed by most writers to prevent premature evaporation and to treat additional soil for use in covering the seed after sowing, these items will further increase the expense of formaldehyde treatment. The expense of steam disinfection of out-of-door seed beds of tobacco is given by Johnson ² as \$7.50 to \$10 per thousand square feet of bed. This is a much higher cost than is to be anticipated with acid or copper-sulphate treatment.

¹ These prices prevailed prior to the outbreak of the European war. It is assumed that the present higher prices are temporary.

² Johnson, James. The control of diseases and insects of tobacco. Wis. Agr. Exp. Sta. Bul. 237, p. 10, 1914.

Sugar, at first glance an excessively expensive amendment for use on soil, is not so much more expensive than formaldehyde in the quantities which appear of value in preventing damping-off at three of the nurseries. If some unrefined sugar-bearing substance could be substituted for the table product used in the experiments, it is entirely possible that for certain soils sugar would become an economically satisfactory treatment for coniferous seed beds. Zinc chlorid also, while probably somewhat more expensive than formaldehyde, is not so costly as to be economically impossible on soils where it may prove to be the most effective disinfectant. Both of these substances are, however, decidedly more expensive than sulphuric acid or copper sulphate.

The most troublesome thing about the treatment with acid is that at some nurseries it is necessary to give treated beds frequent waterings during the germinating period for the protection of the roots of the seedlings against chemical injury. This has been found to be the case in acid plats at three nurseries, and with copper and zinc salts at one nursery, respectively; where these disinfectants have given evidence of greatest commercial value. At one of these nurseries (Halsey, Nebr.) figures are available which indicate the cost of the treatment with acid and subsequent watering. The additional labor cost of the seed sowing, due to the use with it of the acid application, was furnished by the forest officers. The figures follow.

*Additional cost of seed beds at Halsey, Nebr., due to acid treatment, per 1,000 square feet
(space occupied by paths excluded).*

Cost of acid (allowing for freight, drayage, and waste).....	\$1. 00
Additional labor in seed sowing, due to application of acid.....	. 80
Labor cost of extra waterings required by acid beds during germinating period. .	2. 70
Depreciation of containers for applying acid solution, and increased supervisory cost (estimated), not to exceed.....	. 50
Total charge against treatment.....	5. 00

The above figures were obtained in 1912. Subsequent changes in nursery practice have probably changed the costs, but no later figures are available.

This cost of \$5 per 1,000 square feet, or one-half cent per square foot of seed bed, would seem very high if put on an acreage basis. For extensive farming operations it would, of course, be excessive. But because of the very high cost of coniferous seed and the very small area on which the seed-bed operations of even a large nursery are usually concentrated, this cost is easily offset by even a slight increase in the stand of seedlings secured. The actual cost of production of seedlings is seldom less than 50 cents per thousand by the end of the first growing season. The prices commonly quoted by commercial nurseries for seedlings of most species which have remained in the

sced bed for a second year run from four to ten times this figure. If the minimum stand commonly desired, i. e., 100 seedlings per square foot, is obtained on untreated beds, an increase in stand of only 20 per cent will mean an increased production of 20,000 seedlings, of a minimum value of \$10 for the 1,000 square feet taken as a unit. Even in this minimum case, therefore, the treatment may be considered to have paid for itself twice over. The ordinary net results should be still more favorable, for the following reasons:

(1) At nurseries where acid or copper sulphate can be used without especially frequent watering the cost of the treatment will be less than at Halsey. At only one other nursery has it been found necessary to water the treated beds as much as at Halsey.

(2) The average increase in stand resulting from the treatment is much greater than the 20 per cent used in the preceding calculations. Figures based on exact counts for two or more seasons are available from five localities (Halsey, the Kansas sand hills, Garden City, Fort Bayard, and Monument). The average increase in stand resulting from the best treatments at all of these nurseries is exactly 100 per cent.

(3) An additional advantage, of greater value than the average increase in stand, is the stabilization of output through the prevention of damping-off epidemics.

(4) A further advantage is the development of more uniform stands in the beds by the prevention of damping-off patches.

(5) In addition to the advantages from increased stands and decreased damping-off, disinfectant treatment often has incidental results in the way of weed control or of increased growth of the conifers which may by themselves more than pay all costs connected with the treatment. These secondary advantages are discussed in the following paragraphs.

SECONDARY ADVANTAGES FROM DISINFECTANT TREATMENTS.

STIMULATION OF GERMINATION CAUSED BY DISINFECTANTS.

It is common and, in fact, almost invariable with all of the disinfectant treatments which have been successfully used to find a higher germination percentage in the treated plats than in the controls. In some cases this increase in germination (or, more accurately speaking, in the number of seedlings which appear above the soil surface) is very large. Whole groups of treated plats have in some cases given an apparent germination percentage three times that prevailing in the untreated plats in the same group. While such large increases are not common, it is a very frequent thing for the advantage in increased germination to be greater than that resulting from the control of damping-off after germination. (Compare the first and second columns under the head of "Relative results" in Tables I and II.) Such increases are mainly due to the control of parasites by the treatments; in the untreated plats *Pythium* and *Rhizoctonia* kill many seedlings or sprouting seeds before they break through the soil cover. However, in some cases at least, disinfectants, by direct action or by their effect on the soil, appear to cause seed to germinate which would otherwise have remained dormant. The advantage from this apparent stimulation of dormant seed can not be quanti-

tatively separated from the advantage due to the control of parasites. The sum of the results of the treatments in stimulating germination, protecting the germinating seed from parasites, and in preventing damping-off are all cumulatively expressed by the increase in final stand in the treated over the untreated plats at the end of the season.

INCREASED SIZE OF SEEDLINGS CAUSED BY DISINFECTANTS.

At three of the nurseries where experiments were conducted for several seasons it was found that there was a distinct increase in the size of pine seedlings as a result of treatment with sulphuric acid. Immediately after the seedlings come up, the only effect, when there is a noticeable effect, is a decreased growth rate in the acid plats. This effect later disappears, and during the latter part of the season the seedlings normally grow faster in the acid plats than in the controls or in plats treated with most other disinfectants. At the nursery at Halsey during 1912 and 1913, seedlings were measured in five experimental series, three of jack pine, one of western yellow pine, and one of Norway pine. The average of all five shows that the acid caused an increase in height of 37 per cent.

At the nurseries in the Kansas sand hills and at Garden City acid had a much more surprising effect. The results with western yellow pine indicated a moderate increase in the first season's growth, in agreement with the Halsey results, this increase being still distinctly noticeable, at least at the sand-hill nursery, at the end of the second year's growth. But with jack pine at these nurseries unexpectedly large increases were secured. At both nurseries jack pine ordinarily makes a slow growth during the first season. In plats sown in November, 1912, and treated with sulphuric acid early the following spring, the average height of jack pine after a year's growth was found to be more than three times that of the seedlings in the untreated plats. The effect of acid treatment on the seedlings at the Garden City nursery is shown in Plate II, figure 1. At the Kansas sand-hill nursery, root systems as well as tops were examined. The increase in root development appeared entirely commensurate with the increased size of the tops. The air-dry weight of the tops at the sand-hill nursery was $7\frac{1}{2}$ times as great in these acid plats as in the untreated plats.

It is not to be expected that the acid will result in increased growth of any species in all soils, as the effect on growth is apparently due not to direct stimulation of the conifers, but rather to the effect of the acid on the soil. It is interesting to note that the only great increases in growth have been found at the nurseries where the soil water contained the largest quantities of acid carbonates.

The economic value of a moderate increase in growth, such as is secured at Halsey, depends largely on the system of handling stock. If the seedlings are to be held in the seed bed for two years an increase

in the first season's growth is not very important. If, however, it is desired to transplant the stock at the end of the first season the increase in size due to acid, at least in the jack pine, which is ordinarily most helped, may mean the difference between success and failure. In a case of great increase in size, such as was secured by the acid treatment of jack pine at the two nurseries in Kansas, the economic results are more positive. It was entirely impossible to raise 1-year-old stock large enough to transplant without the use of acid. With the acid treatment 1-year-old seedlings were produced which appeared to be in every way the equal of untreated 2-year-old stock for transplanting purposes. The time and expense involved in holding the stock for a second year in the seed beds were avoided. At the Garden City nursery the advantage went even farther than that. The seedlings in the untreated beds were so small that they could not withstand winterkilling and were practically all killed before the second growing season. The seedlings in the acid plats immediately adjacent came through the winter practically without loss. While, as already stated, the acid proved ineffective at this nursery so far as the control of damping-off is concerned, on account of the carbonates present in the soil, its effect on growth and the resultant freedom from winter loss alone positively indicated its use on jack-pine beds in combination with the toxic salts found most valuable for damping-off control.

WEED CONTROL BY DISINFECTANTS.

At the nurseries where weeds are troublesome in the seed beds the effect of the disinfectants on the weeds is probably the most important of the secondary results of the treatment. The plants commonly occurring as weeds seem on the whole much more sensitive to acids and to copper and zinc salts than do the conifers. The result is that treatments so worked out as to be entirely harmless to the coniferous seedlings in the beds are found at a number of nurseries to keep the beds almost entirely free from weeds during the first three or four weeks after the germination of the conifers. This is just the time when most weeds can be expected to appear in the untreated beds and when the delicacy of the young conifers makes it difficult to do even hand weeding without breaking or pulling up many of the seedlings. The economic value of this weed-control feature varies with different nurseries. At some places the efficiency with which weeds are controlled is less than at others. At some places weeds are not numerous enough to make weed control a consideration of any very great importance. The only place at which an attempt has been made to reduce to a dollars-and-cents basis the value of the weed-controlling effect of a damping-off control treatment is at Halsey, Nebr. Approximate figures obtained from forest officers indicate that the entire cost of the hand weeding required during the seasons consid-

ered was approximately \$7.60 per 1,000 square feet; that for the season of 1912 the cost in the acid beds was \$5.40 less than in the untreated beds; and in 1913, \$5.20 less. This saving in cost of weeding exceeds the entire cost of the acid treatment as estimated during the first of these years. While the net value of weed control will not be as great as this in all seasons or at all nurseries, it appears that at several of the nurseries where tests have been carried on the benefit from weed control (Pl. II, fig. 2) or from increased growth of the seedlings, or from both of these effects combined, will be sufficient to more than justify the treatment. In such cases the control of damping-off secured by the treatments will be clear gain. It is especially interesting to note that in the seed beds of the Feather River Forest Experiment Station (California) a light sulphuric-acid treatment is in regular use simply on account of its value as a weed killer, entirely irrespective of any effect on damping-off.

CONCLUSIONS AS TO SOIL DISINFECTANTS.

The results listed in Table III indicate the complexity of the problem of soil treatment to control damping-off parasites. It is at once evident that a single season's experiments conducted on a single soil do not furnish a basis on which it is safe to make recommendations for general use. It furthermore appears that even after as extensive experiments as are here reported, it is not possible to prescribe any one treatment which will be safe and effective at all nurseries. Heat, the disinfecting agent most commonly employed by workers with truck soils, has proved inferior to other methods at all of the nurseries at which it has been tried. Sulphur, which is reported to have given excellent results against certain root diseases of other plants, has on the whole given disappointing results in pine seed beds. Formaldehyde, sulphuric acid, copper sulphate, and zinc chlorid, the four most generally satisfactory substances, have each failed at one or more nurseries. Especially at nurseries where no adequate watering system has been installed the frequent watering which beds treated with acid or with copper and zinc salts sometimes require means considerable trouble and expense.

However, after all these difficulties and drawbacks have been considered, analysis of the results indicates that it will be practicable to control damping-off by some soil treatment at any nursery where it is troublesome. The first part of Table III, containing results at the seven nurseries where repeated tests have been made, is, of course, the most important. At all of these nurseries soil treatment has proved successful. It is significant that at all but one of these seven sulphuric acid has proved successful. The acid failed at the seventh nursery only because of the high carbonate content of the soil, a condition rarely found at coniferous nurseries. At this seventh nursery

the cheap and simple copper-sulphate treatment proved entirely satisfactory, with the alternative of zinc chlorid in case the copper salt should ultimately prove in any way unsatisfactory. At four of the seven, all that appears necessary to be done is to apply the disinfectant, and thereafter let the beds take care of themselves. Although specially frequent watering is required during the germinating season by treated beds at the other three nurseries, the cost of this, as has been shown for Halsey, is not excessive, and the amount of extra watering required to protect the germinating seedlings at the remaining two nurseries is less than at Halsey.

At the localities considered in the last part of the table, where the tests have been mainly or entirely limited to a single season, some facts of interest have been developed, though at none of them have the best control methods been definitely determined. At Dundee and Cass Lake a sufficient number of independent series of tests were made to show without doubt that some one of the treatments which resulted well will be found satisfactory for regular use. At most of the other nurseries in this second division the tests have been preliminary in character and are only indicative. At 13 of the 14 localities listed in the second part of the table, the results of the tests indicated the value of one or more of the treatments tested. At 9 of these 13 the indications were that the disease could be controlled by a treatment which would not make necessary any special watering of the beds. At the one nursery where no results were obtained (Pocatello) sulphuric acid was the only substance tested under proper watering conditions, and its failure is easily explained by the presence of soil carbonates.

Considering separately the soil treatments employed, it appears that there are four reasonably promising disinfectants for use on coniferous seed beds. The writers have experimented with approximately 50 different substances, alone or in combination, in the treatment of seed beds, and these tests, in conjunction with the results of the writers and of others which are summarized in Table III, indicate that the most generally satisfactory substances for such use are sulphuric acid, copper sulphate, zinc chlorid, and formaldehyde, of which the acid is the most promising.

The use of sulphuric acid has been reported at 20 different localities. At 17 of these it has given indications of value. Its failure at Pocatello and Garden City is merely an indication that it will not succeed in the presence of large quantities of soil carbonates. At Glenview, Ill., the tests were very preliminary and therefore not sufficient to show that it was valueless. It has become established as a regular part of nursery practice at all nurseries where it has been repeatedly tested, with the exception noted of the one where the soil contained carbonates. At several nurseries in the

Middle West, where the acid in single-season tests did not give as good results as other substances, there is reason to believe that the results of the acid treatment will be much better in normal seasons. The acid has to recommend it, in addition to its effectiveness against damping-off, the elements of cheapness, efficiency in killing weeds, and in many places of causing an increased growth of the conifers.

Copper sulphate, tested at 11 different places, gave no indications of value at three of them and very doubtful indications at the fourth. At the others it gave more or less indication of value, reaching the stage of regular nursery use at one nursery and at two others giving better results than the acid in single-season tests. Copper-sulphate treatment costs about the same as treatment with acid and is nearly or quite as effective in killing weeds, but has not been observed to result in any marked increase in growth of the conifers.

Data as to the value of zinc chlorid were secured from ten nurseries. At one of these it failed. At three others the tests were very preliminary, and while value was indicated the extent of value was not determined. At four it indicated value, but to a less extent than other treatments used. At the remaining two it indicated sufficient value to rank as a successful treatment. At both of the nurseries where it has been given repeated tests it has proved as good as any other treatment. At both of these, however, it has not been shown to be decidedly better than cheaper treatments (copper sulphate at Garden City and sulphuric acid at Fort Bayard), and therefore is not likely to replace them in regular use. Like copper sulphate, it kills weeds in addition to decreasing damping-off and has not been observed to cause increased growth of the conifers. The relatively high cost of this disinfectant, approximately one-half cent per square foot on heavy soils for material alone, is a point against it. Both copper sulphate and zinc chlorid cause injury to pines on some soils where acid seems entirely harmless. This means that their use will at most places necessitate more watering during the germinating period than is necessary when acid is used.

Data as to the value of formaldehyde in controlling damping-off have been secured from 12 places. At two of these it has failed. At another it has indicated value; extent undetermined. At five others it has indicated less value than sulphuric acid, while at the four remaining places it has been reported as successful.¹ It also kills weeds, has little effect on the growth of pines, and has the advantage of never making necessary any extra watering in treated plats. The points against it, in addition to its inferior efficiency in controlling damping-off at many nurseries, are its high cost and its tendency to kill seed if applied at or near the time of sowing. It is

¹ At Dundee, formaldehyde alone was considered a failure, as the only successful formaldehyde plats were those also treated with zinc chlorid.

necessary to treat beds some time before sowing, this period varying from two days to two weeks in different soils. The generally prescribed practice of covering the beds to prevent reinfection or premature evaporation of the formaldehyde during this period is troublesome and expensive. Further tests may prove it unnecessary.

In considering disinfectants, the ultimate as well as the immediate results should be taken into account. No data are at hand to show the effects of repeated treatments of soil with toxic salts or formaldehyde. The effects of single treatments seem to be purely temporary. Treatments of one-eighth and three-sixteenths ounce of copper sulphate per square foot (equivalent to 341 and 511 pounds per acre, respectively), which are expected to be quite sufficient for use against damping-off at most nurseries, involve additions of only one-sixth and one-fourth, respectively, of the amount which has been used in single treatments at Garden City without any noticeable permanent effect. Sulphuric acid might ultimately bring about an acid condition of the soil if used repeatedly, but this could be easily remedied at any time by the addition of lime. The only possible bad effect of continued use of the acid would therefore be an accumulation of sulphates. The sulphur added in a treatment of three-sixteenths fluid ounce of acid per square foot would be, roughly, 300 pounds per acre. If repeated every year, this would, of course, mean a considerable change in sulphur content. However, it would be a very rare thing for a treatment to be applied two consecutive years on the same soil, and where rotation is practiced five or six years commonly elapse between the growing of two crops of seedlings of susceptible species on the same soil. This minimizes the likelihood of any bad cumulative effect by the treatments.

The comparison of the four disinfectants considered in the foregoing paragraphs does not make possible a final statement as to their relative value. At most of the localities listed in Table III there have not been enough tests to give conclusive results. It is believed from the somewhat incomplete evidence secured that at most nurseries soil treatment with sulphuric acid will be found a satisfactory and probably the most satisfactory means of decreasing damping-off and that where it is not satisfactory success can be secured with some one of the other disinfectants—copper sulphate, zinc chlorid, or formaldehyde.

It is, of course, recognized that the treatments so far devised are not as simple and effective as are desired. Further tests of these disinfectants and of numerous others are under way. The problem of damping-off control is also being attacked from other directions than that of simple soil disinfection. It is hoped that a single disinfection method may be found which can be used on any soil and which will not require any unusual precautions against chemical injury; or, failing this, that some less direct procedure against the parasites

will be found satisfactory. The securing of final results along these lines will of necessity require several years' experimenting, because of the differences between different soils and the number of species of parasites and of conifers which have to be considered. Meantime, the foregoing results are published to enable nurserymen to make use of the experience already gained. Under the following heading are outlined a number of treatments, at least one of which should be found successful and profitable at any coniferous nursery where damping-off is prevalent.

SOIL TREATMENTS RECOMMENDED.

No treatments can be guaranteed as either safe or effective on all soils. However, it is nearly certain that for any nursery at least one of the following will be found successful. It is therefore recommended that any nurseryman who has serious losses from damping-off test some of these treatments on a small scale until he finds which one is best suited to his conditions. At least two successful tests should be made before a treatment is judged safe for large-scale use.

Treatments for heavy soils.

1. Sulphuric acid, three-sixteenths fluid ounce per square foot of bed, dissolved in from 1 to 2 pints of water per square foot of bed and applied immediately after the seed is sown and covered.

2. Same as treatment 1, but use one-fourth ounce acid per square foot.

3. Copper sulphate, one-eighth avoirdupois ounce per square foot, dissolved in water and applied immediately after the seed is sown and covered.

4. Same as treatment 3, but use three-sixteenths ounce per square foot.

5. Zinc chlorid, one-half ounce per square foot, dissolved in water and applied immediately after the seed is sown and covered.

6. Formaldehyde, one-half fluid ounce per square foot, dissolved in water and applied 10 days before the seed is sown. Keep the bed covered with paper, tarpaulin, or tight shade frames during these 10 days. Do not spade up formaldehyde beds after treatment. If necessary to cover the seed with soil from outside of the plat, which has not been treated, use subsoil just dug up from at least 1 foot below the surface.

7. Same as treatment 6, but apply the treatment only three days before sowing and do not cover with paper.

8. Air-slaked lime, one-half avoirdupois ounce per square foot, applied dry and raked into upper 3 inches of soil just before sowing. (If hydrated lime is used, three-eighths ounce per square foot will be sufficient.) Immediately after seed is sown and covered apply three-tenths ounce of sulphuric acid per square foot, dissolved in water.

9. Same as treatment 3, but use one-fourth ounce per square foot.

In dissolving disinfectants, use sufficient water to make from 1 to 2 pints of solution per square foot. Two pints should be used if the soil is dry; 1 pint is sufficient when the soil is wet.

Treatments for sandy soils.

1. Sulphuric acid, one-eighth fluid ounce per square foot, dissolved in water and applied immediately after the seed is sown and covered.

2. Same as treatment 1, but three-sixteenths ounce per square foot.

3. Copper sulphate, one-tenth avoirdupois ounce per square foot, dissolved in water and applied immediately after the seed is sown and covered.

4. Same as treatment 3, but one-sixth ounce per square foot.

5. Zinc chlorid, five-sixteenths avoirdupois ounce per square foot, dissolved in water and applied immediately after the seed is sown and covered.

6. Formaldehyde, five-sixteenths fluid ounce per square foot, dissolved in water and applied 10 days before seed is sown. Keep the bed covered with paper or tarpaulin during these 10 days. Do not spade up formaldehyde beds after treatment. If necessary to cover the seed with soil from outside of the plat, use subsoil just dug up from at least 1 foot below the surface.

7. Same as treatment 6, but apply only three days before seed sowing and do not cover beds with paper.

8. Air-slaked lime, three-eighths avoirdupois ounce per square foot, applied dry and raked into the upper 3 inches of soil just before sowing. (If hydrated lime is used, three-tenths ounce per square foot will be sufficient.) Immediately after the seed is sown and covered, apply one-fifth ounce of sulphuric acid per square foot, dissolved in water.

In dissolving disinfectants for sandy soils, use sufficient water to make from 1 to 1½ pints of solution per square foot. One and one-half pints should be used if the soil is dry; 1 pint is sufficient if the soil is already wet.

GENERAL DIRECTIONS FOR TREATMENTS.

Commercial or technical grades of all the disinfectants are satisfactory. The sulphuric acid purchased should be concentrated, having a specific gravity of at least 1.82, while the formaldehyde solution, or "formalin" as it is sometimes called, should be the strongest obtainable, so-called 40 per cent solution, containing 37 per cent by weight. All disinfectants should be kept from the air as much as possible, as they change in strength if exposed. Copper sulphate requires the least care in this respect. *Acid should be dissolved by pouring it into the water—never by the reverse process.* Copper sulphate is quickest dissolved by putting it in a burlap sack and hanging it in the water just below the surface. Both of these solutions are corrosive to metal and should be handled only in wooden or earthenware containers and applied with sprinklers which have been coated inside with hot paraffin.¹ Acid is also hard on the hands and clothes. Men who use it on a large scale are very careful to keep their shoes heavily greased. Canvas gloves treated with hot paraffin or with a mixture of paraffin and a lighter grease, such as vaseline or lard, should be a valuable protection for the hands. The charring of wooden containers used in making up dilute acid solutions probably can be largely prevented by washing them out well with water containing washing soda before they

¹ To coat a sprinkler with paraffin, get the cake paraffin sold by grocerymen for use in sealing jelly and preserves. Shave off some of the paraffin into the sprinkler, and heat the sprinkler till all the paraffin is melted. Then turn the sprinkler around so that the liquid paraffin runs over the entire inside surface and finally pour what is left of the paraffin out through the spout. The whole can should be hot during the process, so that the paraffin will leave a thin coating; a thick coating cracks off too easily. The holes in the sprinkler head will have to be cleaned out with a pin or toothpick after the paraffin has hardened.

are put away at the close of work. A coating of linseed oil, very thoroughly dried, should also prevent the charring of wood. Acid which gets on the hands does no harm if washed off at once with water. In applying treatments on a large scale the sprinklers used should have the holes in the rose or sprinkler head enlarged, to permit faster work.

In trying out the treatments in the foregoing lists, Nos. 1 and 2, the most promising, should be tested first. If both fail, the other treatments should be tried. If the acid solutions cause the soil to effervesce, some of the other treatments should be tried at once, as on such a soil the acid is likely to fail.

The treatments should be applied to small plats which are intermingled with untreated plats for comparison. For test plats, 3 by 4 feet has been found a convenient size. Good results can be obtained with even smaller areas than this, but all plats should be at least 2 feet wide. An arrangement of plats which the writers have found satisfactory is shown in figure 1. The seed for each plat, treated and untreated, should be measured out separately, so that all plats will get equal quantities of seed. Then the number of seedlings living on each plat at the end of the season will show which treatment is most valuable. In watering, shading, and in every other way treated plats should be handled just like the untreated beds, to make the test a fair one.

As soon as the seedlings begin to drop their seed coats, plats treated with acid, copper sulphate, or zinc chlorid should be examined for chemical injury to the roots of the seedlings.¹ If such chemical injury is found to occur, two courses will be open: (1) To test the same treatment again, watering the treated plats thoroughly every day from sowing till germination is complete; or, (2) to abandon the treatment which caused injury and try to get sufficient control of the disease by a weaker treatment or by another dis-

infectant. Treatments 6, 7, and 8 are inserted especially for use at places where acid causes injury and where frequent watering is not practicable; they are reasonably certain not to cause injury to seedlings under any circumstances.

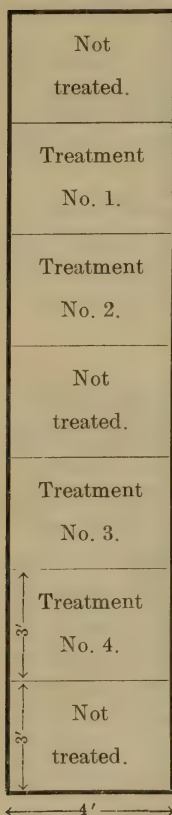


FIG. 1.—Suggested arrangement of test plats.

¹ The method of detecting chemical injury and illustrations of injured and uninjured seedlings have been given in a previous publication: Hartley, Carl. Injury by disinfectants to seeds and roots in sandy soils. U. S. Dept. Agr. Bul. 169, p. 9, pl. 1. 1915. This bulletin can be obtained by sending 5 cents in coin to the Superintendent of Documents, Government Printing Office, Washington, D. C.

SUMMARY.

(1) By damping-off is meant the killing of very young seedlings by parasitic fungi. It is the most serious difficulty encountered in raising coniferous seedlings.

(2) To decrease losses from the disease excessive moisture and shade should be avoided. Caution must be used in following this recommendation or many seedlings may be killed by drought or by white-spot injury to the base of the stem. Damping-off can often be decreased by putting beds on very sandy soil. Seed should not be sown any thicker than necessary. It appears better to sow broadcast than in drills. Late fall sowing results in decreased losses at some nurseries and is worth trial. Proper attention to all of these measures will decrease the losses from damping-off, but at most nurseries they are not sufficient really to control the disease.

(3) The addition of lime, wood ashes, and in some cases nitrogenous fertilizers seems to increase damping-off. Soil alkalinity appears to favor the disease. No effect has been noted from green manures. The use of unrotted stable manure has had very bad results; properly rotted manures seem less objectionable. Tankage, charcoal, and cane sugar are the only nondisinfectant substances which to date have given any hope of disease control.

(4) Soil disinfection has so far proved the best method of combating damping-off. Of many methods tested, treatments with sulphuric acid, copper sulphate, zinc chlorid, and formaldehyde have proved the most satisfactory. The disinfectants behave quite differently at different nurseries. The results of treatments at many different localities are summarized in Table III. The acid has on the whole given the best results. Heat disinfection has been only partly effective. Disinfection by acid or copper sulphate is cheaper than by the other methods commonly recommended.

(5) In addition to decreasing damping-off after the seedlings come up, the chemical disinfectants above mentioned, when properly used, cause an increase in the apparent germination and are very helpful in controlling weeds. This latter effect alone at some nurseries pays the entire expense of the treatment. Sulphuric acid has, furthermore, at some places resulted in marked increases in the late-season growth of pines. (See Pl. II.)

(6) In some soils formaldehyde kills dormant seed, and the other three most satisfactory disinfectants at some nurseries kill the root tips of germinating seedlings. By proper precaution, all such injury may be prevented.

(7) The results obtained to date show that it is entirely possible and practicable to control damping-off by soil disinfection. Unfortunately, the varying behavior of disinfectants at different places

renders it impossible to recommend any single treatment which will be everywhere successful. Directions are given for simple tests, by which it is believed that any nurseryman can develop a treatment that will succeed under his conditions.

(8) Further experiments are being conducted, with the hope of discovering either a more generally applicable disinfectant method than any of those so far tested or else a means of controlling the disease without the use of disinfectants.

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A PRELIMINARY REPORT ON THE OCCURRENCE OF WESTERN RED-ROT IN *PINUS PONDEROSA*.

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INTRODUCTION.

In the national forests of Arizona and New Mexico a varying percentage of the trees of western yellow pine (*Pinus ponderosa*) is affected by an undescribed heart-rot, known locally as red-heart, red-rot, gray-rot, top-rot, and heart-rot. The amount of this rot present varies materially with the exposure, slope, and soil on which the yellow pine is growing, as well as with the age of the timber itself. It is the main heart-rot found in western yellow pine in Arizona and New Mexico and causes an annual loss of thousands of dollars.

This heart-rot is here called "western red-rot" in order to distinguish it from the true red-heart or red-rot, a very similar heart-rot common in many species of conifers throughout the world. True red-rot or ring scale is caused by *Trametes pini*, while western red-rot is produced by an entirely different fungus.

DESCRIPTION OF WESTERN RED-ROT.

CROSS-SECTIONAL VIEW.

Western red-rot may show in the end of a freshly cut log any one of the following stages: (1) An early stage, in which the heartwood is firm but shows reddish to dark-brown discolored areas. Such

areas are often fan shaped and radiate outward from the center of the log, like spokes from the hub of a wagon wheel, or they may be isolated and occur anywhere in the heartwood. (2) A more advanced, or what might be called an intermediate stage, of the rot, in which the affected heartwood is whitish or grayish in color and is so disintegrated that small pieces can be pulled out. The rotted wood consists of soft white strands of cellulose, intermixed with less rotted wood particles. The rotten wood in this stage is often so wet and soggy that water can be squeezed out of it. The white-rot or gray-rot stage is usually in the center of the log and is often surrounded by the brownish fanlike areas seen in the first stage of the rot. (3) A third or final stage of the rot, in which much of the heartwood has been destroyed, leaving the remainder in a very brittle, rotten condition, so that it easily crumbles when handled. In this final stage of the rot all of the cellulose has been absorbed by the fungus, while the wood particles left are reddish to dark brown in color. This stage sometimes occupies only a small portion of the heartwood in the center of the log and may be surrounded by one or both of the other stages.

LONGITUDINAL-SECTION VIEW.

In a longitudinal section, as seen in sawed lumber, the different stages of the rot gradually merge into one another. In the place where the fungus entered the tree will be found the oldest stage which the rot has reached in that particular lesion. If the entire lesion originated from only one center of infection (one dead branch) and the rot has been in the tree for many years, then the three stages described will probably be represented in the one lesion, which may be anywhere from 12 to 20 feet long. There will usually be some 6 to 10 feet in the center of the log which belong to the second and third stages of the rot, while the extremities of the rot lesion will consist of the first stage of the rot.

DEVELOPMENT OF WESTERN RED-ROT IN THE TREE.

This rot advances nearly as rapidly radially as it does longitudinally in the heartwood of the affected tree. Its radial development in the wood is rather peculiar. From the central cylinder of the rot, at irregular intervals along its entire length, narrow radial patches of rot extend outward toward the sapwood. These radial patches are the fanlike or spokelike discolored areas on the end of the log, described under the first stage of the rot. The centers of these radial patches usually consist of whitish delignified tissue, bordered by reddish to dark-brown areas of heartwood which have not yet been delignified but are in the early stages of the rot. Often some of the cellulose in the center of these patches has been entirely absorbed, leaving small irregular cavities extending to the sapwood.

From these radial patches the rot spreads in all directions, until finally the entire heartwood is involved. In tangential sections these radial patches of rot appear as irregular elliptical reddish to brown areas with white centers. These areas are two to several times longer than broad, with their greatest diameter lying parallel with the grain of the wood. There is often a small cavity bordered by the unabsorbed remnants of the delignified tissue in the center of each rotted area. Usually two to six of these discolored areas are grouped together, giving the sawed lumber a very peculiar appearance.

COMPARISON OF WESTERN RED-ROT AND TRUE RED-ROT.

When examining the rot in the end of a freshly cut pine log it is often difficult to determine whether it is western red-rot or true red-rot. A longitudinal view of the rot, however, usually will settle the question beyond any reasonable doubt, since the following constant characters are then in evidence: (1) True red-rot, or red-heart, caused by *Trametes pini*, has many small but sharply defined pockets, or cavities, in the heartwood, lying parallel to the grain of the wood, while western red-rot never has these typical pockets. (2) The attacked wood in true red-rot is usually very firm, even in the final stage of the rot, while western red-rot in its last stage is much disintegrated and easily crumbles when handled. (3) The mycelium of true red-rot when growing in heartwood which is more or less exposed to the air is brown, while the mycelium of the western red-rot is always white. (4) The attacked heartwood in true red-rot never becomes wet and soggy, as it often does in certain stages of western red-rot.

CAUSE OF WESTERN RED-ROT.

The fungus which causes western red-rot never forms brown, woody, perennial fruiting bodies on the boles of living affected pine trees, as *Trametes pini* does, but forms annual fruiting bodies, which are usually developed as white encrusting layers on the under side of logs lying on the ground. This fungus is also the main agent in rotting the sapwood of the cull logs and large branches of the yellow-pine slash.¹

The fruiting bodies, or sporophores, of this fungus, as they occur in Arizona and New Mexico, are usually resupinate, with a hymenial layer consisting of minute tubes or pores. However, fruiting bodies have been found which have distinct and well-formed pilei. The pileate form of the fungus resembles very closely *Polyporus ellisianus* (*Tyromyces ellisianus* of Murrill in North American Flora); the

¹ Long, W. H. A new aspect of brush disposal in Arizona and New Mexico. In Proc. Soc. Amer. Foresters, v. 10, no. 4, p. 383-398. 1915.

writer, however, does not wish to call it by this name until the investigations now under way as to its identity are completed.

Lloyd reports a specimen of the same fungus from the State of Washington, collected by J. M. Grant,¹ and refers it to *Polyporus ellisianus*. The writer (through the kindness of Mr. Lloyd) has been able to examine a portion of the collection from Washington, and it agrees in all essential characters with the fungus which causes western red-rot in Arizona and New Mexico. Concerning the host of the Washington specimen Lloyd writes, "There was no note with the specimen regarding its host, excepting that it grew on a pine of some kind."

A sporophore of what is apparently the western red-rot fungus has been examined from Idaho.

Von Schrenk² in 1903 published a figure of a heart-rot of living trees of *Pinus ponderosa* from the Black Hills Forest Reserve in South Dakota, which is typical of the second stage (cross-sectional view) of this rot as it occurs in yellow pine in New Mexico and Arizona. It is therefore highly probable that this fungus is widely distributed throughout the West, both as a saprophyte in slash and dead trees and as a heart-rot in living timber. The writer has examined a specimen of the same fungus collected in New Jersey on *Pinus* sp. and one of both fungus and rot from Vermont on *P. strobus*.

ENTRANCE OF WESTERN RED-ROT INTO LIVING TREES.

The western red-rot fungus enters the living tree through dead branches in the crown. It first attacks the sapwood of the dead branch; then the heartwood. It then travels down the sapwood and heartwood of the dead branch into the heartwood of the living tree. Once established in the tree, the fungus apparently continues to grow as long as the tree is alive, spreading in all directions, until often the heartwood of the entire bole of the tree, as well as that of the large branches, is invaded and rendered worthless for lumber.

EXTERNAL SIGNS OF WESTERN RED-ROT.

No external signs were found which would absolutely determine whether or not a given standing yellow-pine tree was defective. Trees having large dead branches intermixed with living limbs and ragged and unhealthy looking crowns were often attacked by western red-rot. Such defective trees were usually located on very thin soil on steep south or east slopes, where growth conditions were very poor. However, many trees which showed no recognizable external evidences of decay were found to have western red-rot when they were felled.

¹ Lloyd, C. G. Mycological writings, v. 4, letter no. 60, p. 4. 1915.

² Schrenk, Hermann von. The "bluing" and the "red rot" of the western yellow pine, with special reference to the Black Hills forest reserve. U. S. Dept. Agr., Bur. Plant Indus. Bul. 36, p. 34, 40, pl. 14, fig. 2. 1903.

AREAS EXAMINED FOR WESTERN RED-ROT.

Before marking an area for cutting it should be determined whether the rotation is to be short, medium, or long. Often the amount and character of the defect present in the timber will be an important factor in determining what rotation is best for the area in question, especially in stands of virgin timber.

In order to throw some light on the presence of defects, especially western red-rot, in western yellow pine and its probable influence on the rotation period, studies were conducted on certain areas in the Santa Fe National Forest where both tie trees and saw timber were being cut. The main problem which demanded immediate attention was the relative amount of rot present in the black jack on these areas compared to that in the yellow pine. The special areas examined were located in Cienega, Ocho, Amole, Gallegos, and La Junta Canyons and on adjacent mesas, all of which are situated in the Cienega ranger district. The data given here were obtained mainly from Cienega, Ocho, and Amole Canyons on areas which had been cut for hewn ties. A small area near the Cienega ranger station on which both ties and saw timber had been cut was also examined for rot. The tie trees ranged from 10 to 16 inches, d. b. h., while those over these diameters were saw timber. These areas were especially suitable for a study of this character, since an unusually large percentage of the black jack (30 to 50 per cent) and nearly all of the yellow pine (85 to 100 per cent) were being cut.

There are two forms of western yellow pine called, respectively, black jack and yellow pine. Black jack is the form which this pine assumes before it reaches the age of 125 to 150 years.¹ During this period its bark is blackish to dark brown, with narrow furrows, while the yellow-pine form has lighter colored, widely furrowed bark.

NUMBER AND KIND OF TREES EXAMINED.

In the vicinity of the Cienega ranger station, 1,691 felled black jacks and 547 felled yellow-pine trees were examined for rot. In addition to this, all of the trees 4 inches, d. b. h., and over on a sample strip 1 chain wide and 140 chains long, located on the mesa between Ocho and Cienega Canyons, were tallied by the district marking board of the Forest Service, carefully examined, and any evidences of disease or defect noted. One hundred and twenty-four felled black jacks (10 to 16 inches, d. b. h.) and 16 felled yellow pines (12 to 16 inches, d. b. h.) had been cut for hewn ties on this sample strip.

Table I shows the number of sound and defective trees on each of the areas examined and in a general way the character of the

¹ Woolsey, T. S., jr. Western yellow pine in Arizona and New Mexico. U. S. Dept. Agr., Forest Serv. Bul. 101, 64 p., illus, 4 pl. 1911.

site on which the trees were located. The amount of butt-rot (probably caused by *Polyporus schweinitzii*) present on the areas examined was so small that it was not included in the table. This explains any apparent discrepancy between the sum of the sound and defective trees and the total number of trees listed in the table.

TABLE I.—Data on sound and defective felled trees of black jack and yellow pine.

Area.	Kind of timber.	Number of trees.	Sound trees.		Defective trees (western red-rot).		Remarks.
			Number.	Per cent.	Number.	Per cent.	
1	{Black jack.....	210	206	98	4	1.9	{Top of ridge; growth conditions fair, mainly black jack.
	{Yellow pine.....	20	18	90	2	10	
2	{Black jack.....	294	293	99.66	0		{Lower portion of southeast slopes and bed of canyon; growth conditions fair.
	{Yellow pine.....	84	73	86.9	10	11.9	
3	{Black jack.....	126	124	98.4	2	1.6	{South and southeast slopes; thin soil; slopes steep, rocky; growth conditions poor.
	{Yellow pine.....	132	87	65.9	40	30.3	
4	{Black jack.....	206	193	93.7	9	4.3	{South and east slopes; thin soil; slopes steep; growth conditions poor.
	{Yellow pine.....	76	57	75	14	18.4	
5	{Black jack.....	855	836	97.7	14	1.6	{Mesas; soil good; growth conditions good.
	{Yellow pine.....	235	223	94.9	8	3.4	
6	{Black jack.....	124	123	99.2	0		{14-acre sample strip across mesa; growth conditions fair.
	{Yellow pine.....	16	13	81.25	3	18.75	
1-6	{Black jack.....	1,815	1,775	97.8	29	1.59	{Total for all areas.
	{Yellow pine.....	563	471	83.6	77	13.6	
	{Both kinds.....	2,378	2,246	94.4	106	4.5	

DISCUSSION OF THE DATA PRESENTED IN TABLE I.

A study of Table I shows several interesting facts: (1) There is a marked difference in the percentage of black jack and of yellow pine affected by western red-rot. (2) The site seems to have a decided influence on the occurrence of this rot, especially in the yellow pine. (3) The variation in the percentage of western red-rot on the different areas shown in the table is due to several factors, the three most prominent ones being the relative proportion of black jack and yellow pine which had been cut on each area, the influence of the site on the growth of the trees, and the age of the timber. For instance, on area No. 3 the percentage of this rot in yellow pine is high, due apparently to unfavorable growth conditions and the age of the timber cut.

Table I should give a fairly accurate idea of the occurrence of western red-rot in black jack of merchantable size in this region, since 1,855 trees of this kind were examined over areas where 30 to 50 per cent of the black jack 11 inches, d. b. h., and over had been cut. As an indication of the amount of this rot present in the yellow pine, Table I is not so conclusive, since, with the exception of areas 3 and 4, all of the yellow pine shown in the table was of small diameter (12 to 18 inches, d. b. h.) and was cut for hewn ties only. This means that the percentage of trees showing western red-rot in the yellow pine on these areas will be greater than is shown in the table, except

areas 3 and 4. The older the trees are, the greater the amount of rot present, since such trees have had more opportunities for infection than younger trees. However, taking the area as a whole, probably 20 per cent of the yellow-pine trees (exclusive of black jacks) will show western red-rot in some portion of the bole. The areas shown in this table are mainly covered with black jacks intermixed with only a small number of yellow pines. For instance, in the sample strip, 1 chain wide and 140 chains long, 195 black jacks were marked for cutting and 1,270 left, a total of 1,465 black jacks 4 inches, d. b. h., and over, while 108 yellow pines were marked and 22 left. Of the 1,465 black jacks present on this area, there were 605 trees of merchantable size (10 inches, d. b. h., and over) to only 130 yellow pines. This means that on such areas the percentage of western red-rot in the merchantable timber will be small compared to similar areas where the proportion of yellow pine is greater than that of black jack.

WESTERN RED-ROT IN BLACK JACK AND YELLOW PINE.

The percentage of western red-rot in black jack for all the areas is very small, since only 29 trees out of 1,815 (1.59 per cent) showed this rot, while in yellow pine it was much greater, 77 trees out of 563 (13.6 per cent) being infected. Even then, this percentage is not high when compared with some other areas in Arizona and New Mexico. For instance, on certain sale areas on the Upper Pecos River, 70 to 95 per cent of the yellow-pine trees were attacked by western red-rot. Since this rot enters mainly through dead branches it is easily seen why fewer black jacks are attacked by it than yellow pines. The total percentage of trees attacked by western red-rot, both black jack and yellow pine, is only 4.5 per cent for all the areas shown in Table I.

Of the black jacks infected with western red-rot, nearly all were suppressed or grown under very unfavorable conditions. This indicates that all such trees should be marked for cutting when possible, not only on account of their susceptibility to this rot, but also because they will never make strong, thrifty trees. When the soil is deep and capable of producing vigorous growth in the trees, western red-rot is present only in a small degree unless the trees are very old and overmature. Such soil conditions are found on many of the mesas and near the bottoms of small canyons. There is always a marked increase in the amount of western red-rot in yellow pine growing on very steep slopes and on poor, thin soil.

WESTERN RED-ROT AND THE ROTATION FOR WESTERN YELLOW PINE.

As to the relative efficiency of a long rotation and of a medium or short rotation period in finally eliminating this rot from the forest, the answer is very evident, judging from the viewpoint of the rot

alone. Table I clearly shows that during the black-jack period the trees are practically free from this rot, but as they grow older the increasing number of dead branches makes them more open to the attacks of this fungus; that is, after the trees enter the yellow-pine stage of their growth they are more and more subject to infection by heart-rotting fungi.

In the Cienega ranger district western yellow-pine trees up to 125 or 150 years old (the black-jack period) are rarely attacked by western red-rot, for the reasons previously given, while trees over 200 years old show a much higher percentage of rot than the younger trees (black jack). Any system of cutting that will take out most of the older trees (yellow pine) and many of the larger black jacks, as well as all suppressed trees, will do much to rid the future forest of this serious heart-rot. It also follows that a short rotation will be better for the future health of the forest so far as heart-rots are concerned. It is a fundamental fact that the older a tree is, the more liable it is to be attacked by heart-rotting fungi.

SUMMARY.

(1) A varying percentage of western yellow pines in Arizona and New Mexico is affected by a serious heart-rot called in this bulletin western red-rot.

(2) Western red-rot has three stages in its development: (*a*) An initial stage, in which the affected heartwood is firm but shows reddish to dark-brown discolored areas; (*b*) an intermediate stage, in which the diseased heartwood is whitish or gray in color and more or less delignified; (*c*) a final stage, in which much of the heartwood has disappeared, owing to the absorption of the delignified portions, while the wood particles left are brittle and crumble easily when handled.

(3) Western red-rot attacks both the sapwood and the heartwood of dead branches on living trees. It then travels down the dead branches into the heartwood of the living tree.

(4) No constant external signs were found which would absolutely determine whether or not a given living yellow-pine tree was attacked by western red-rot. However, trees growing on very thin soil on steep south or east slopes where growth conditions are very poor have a higher percentage of this rot than yellow pines situated where the growth conditions are good.

(5) Of the 1,815 black jacks examined for western red-rot, only 29, or 1.59 per cent, had this rot, while out of 563 yellow pines examined, 77, or 13.6 per cent, were attacked by this rot.

(6) So far as heart-rots are concerned a short rotation is better for the future health of the forest than a long one.



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WM. A. TAYLOR, Chief



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INVESTIGATIONS OF THE ROTTING OF SLASH IN ARKANSAS.¹

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INTRODUCTION.

Two very important factors must be considered in administering timber-sale areas, viz, the conservation of the present second growth and the leaving of the area in the best possible condition for future reproduction. The particular method of brush disposal over such areas is therefore of importance from the reproduction viewpoint. In the semiarid regions of the Southwest the dominant factor governing reproduction is the obtaining and conserving of sufficient moisture to germinate the seeds and to carry the seedlings over the first four or five years of their existence. In the forests of Arkansas the conservation of the moisture is of minor importance, since the annual rainfall is usually sufficient to supply all of the moisture necessary for the germination of the seed and for the continued growth of the seedlings.

Fire is a very important factor from a reproduction viewpoint in the National Forests of Arkansas. The Ozark National Forest consists almost exclusively of mixed stands of timber in which hard-

¹ The writer is under obligations to Mrs. Flora W. Patterson and Drs. E. A. Burt, C. L. Shear, and W. A. Murrill for assistance rendered in identifying many of the fungi mentioned in this bulletin.

wood trees usually predominate, while the Arkansas National Forest is dominated by pines. The annual leaf fall from the deciduous trees accumulating year after year on the ground and the large growth of underbrush present constitute a perpetual fire menace. Even on areas in these two forests where shortleaf pine (*Pinus echinata*)¹ is being logged there are usually enough deciduous trees and underbrush present to make a ground litter from the fallen leaves, to which must be added the usual leaf litter found under pine trees.

The method of brush disposal that will give to the reproduction over these areas protection from fire and yet leave as much as possible of the forest litter, leaves, twigs, etc., on the ground to rot, thereby adding fertility to the soil and protecting it against excessive erosion by restraining the run-off, is the one that should be adopted. The best method of brush disposal when the slash remains on logged areas is that which leaves the brush in such a condition that it will rot most rapidly, thus removing as soon as possible the fire menace from this source.

METHODS OF BRUSH DISPOSAL.

The three methods of brush disposal discussed in this bulletin are (1) pulling, (2) piling, and (3) scattering.

By "pulling" is meant that the brush in the tops of the felled trees is not lopped, but is left exactly as the tree tops fall except when they fall on or near reproduction. When brush is too close to reproduction it is pulled away from the young trees and merchantable timber, to decrease the danger from possible fire; hence the term "pulled brush."

The terms "piling" and "scattering" are self-explanatory.

Piling is the usual method of brush disposal followed in the National Forests of Arkansas. However, a few Forest Service areas were examined where the brush had been scattered as an experiment. In this State pulling the brush has not yet been practiced on Government sales, but on alienated or patented lands all of the brush in the tops of the felled trees is generally left as it falls. This is really a combination of "pulling" and "scattering," since the tops are left unlopped while the branches cut from the merchantable portion of the bole are scattered on the ground. The character and rate of rotting of the brush left on these private areas will therefore be the same as when the brush is pulled or scattered.

This bulletin deals specifically with the rapidity with which the brush rots and with the fungi causing this rotting under each of

¹ The nomenclature for trees used in this paper is that of George B. Sudworth. (Check list of the forest trees of the United States, their names and ranges. U. S. Dept. Agr., Div. Forestry Bul. 17, 144 p. 1898.)

these methods. It will be necessary in discussing the various methods of brush disposal to take into consideration the types of timber being cut. In the Ozark National Forest the main timber is white oak (*Quercus alba*) intermixed with black oak (*Q. velutina*), post oak, (*Q. stellata*), and several other species of minor importance, while on certain areas some shortleaf pine is found. In the Arkansas National Forest the bulk of the timber to be logged is shortleaf pine.

The investigations of the rotting of slash in Arkansas were carried on in the Arkansas and Ozark National Forests on areas which had been logged from 1 to 10 years. All of the areas examined which had been logged for more than five years were on private or patented lands, but located within these National Forests. The conclusions reached from these studies should be applicable to all of the other areas in these two forests, since the underlying principles are identical and the climatic conditions very similar.

WHITE-OAK SLASH.

FUNGI WHICH ROT THE SLASH.

Four main fungi were found rotting the white-oak slash, viz, *Stereum rameale*, *S. versiforme*, *S. umbrinum*, and *S. fasciatum*. All are sap-rotting fungi which cause but little apparent change in the texture of the wood. They produce what might be called indeterminate rots, since there are no well-defined characteristics which mark any one of them. All slightly discolor the wood, which later becomes whitish in color, lighter in weight, and easily broken. Strange to say, each of these fungi rots its own special portion of the slash. *Stereum rameale* is usually found attacking twigs which bear the leaves and very small branches (1 inch or less in diameter). This fungus seems to begin on the twigs and works gradually down them to where the branches are about 1 inch in diameter; there two other fungi (*S. versiforme* and *S. umbrinum*) take up the work and rot the small branches up to 2 or 3 inches in diameter, where a fourth fungus (*S. fasciatum*) usually begins its attack on the wood. This is the main fungus which rots the sapwood of the logs and large branches 3 inches or more in diameter, and it is often found rotting the sapwood of the stumps as well as the boles and large branches of standing dead oak trees. None of these fungi destroys the attacked wood completely, its final disintegration being left to other groups of fungi, insects, etc.

The heartwood of the large branches and trunks remains for many years after the sapwood is destroyed, but meantime it is being slowly rotted by a delignifying fungus (*Stereum frustulosum*), which produces small cavities or pockets in the wood.

Other fungi of minor importance were found attacking the oak slash, the most important of which was a small, dark-brown, gelat-

inous fungus (*Exidia glandulosa*) found at irregular intervals along the twigs and small branches. Its action on the wood is to produce whitish rotten areas, usually extending entirely through the branch, thus forming a line of weakness which ultimately causes the branch to break into small sections (2 to several inches long). These pieces fall to the ground, where complete disintegration follows.

Merulius corium, *Hymenochaete curtisii*, *Diatrype stigma*, and *Stereum hirsutum* are other fungi occasionally found attacking the twigs and small branches, while *Merulius tremellosus*, *Polystictus pergamenus*, *P. versicolor*, *Polyporus gilvus*, *P. cinnabarinus*, *P. benzoinus*, *Lenzites betulina*, *Flammula* sp., *Panus stipticus*, *Stereum spadicium*, *Lycoperdon pyriforme*, *Xylaria hypoxylon*, and several species of *Poria* are occasionally found rotting logs, stumps, and large branches.

Panus stipticus, *Flammula* sp., *Merulius tremellosus*, *Xylaria hypoxylon*, and *Lycoperdon pyriforme* are fungi which apparently attack wood which has been more or less rotted by other fungi.

Polystictus pergamenus, *P. versicolor*, *Polyporus gilvus*, *P. cinnabarinus*, *P. benzoinus*, and *Lenzites betulina* rot both the sapwood and heartwood, but unfortunately none of them are common on oak slash in the forests of Arkansas. None of the fungi found rotting the oak slash produces a heart rot in the living tree. However, certain fungi which cause heart rots in living oak trees will continue to grow in the infected wood after the trees are felled. The most important of these are *Hydnum erinaceus*, *Polyporus pilotae*, *P. sulphureus*, and *Stereum subpileatum*.

BRUSH WHEN PULLED.

Soon after a living tree is felled, wood-boring insects and various fungi begin their work of disintegration and decay. The first evidence of fungous activity in slash is a discoloration of the sapwood in the twigs, branches, and trunks, which usually begins a few months after the trees are felled. Marked evidences of decay in the shape of well-defined rotten spots and areas in the wood and the formation of fruiting bodies or sporophores of the wood-rotting fungi do not appear until one or two years after the trees are felled.

All of the leaves in the tops of felled oak trees will usually fall in from one to three years, depending more or less upon the age of the leaves at the time the oak was cut and to a slight extent on the locality in which the timber is situated.

The small branches and twigs gradually rot, and the majority of them will have fallen to the ground at the end of four years. By the end of six years practically all of the branches in the tops will have rotted and fallen except some of the very large ones which have much heartwood. Also, practically all of the sapwood in the boles and cull logs will have rotted away during this time.

BRUSH WHEN PILED.

White-oak brush piles were examined, ranging from 1 to 5 years in age. During the first year after the trees were cut but little evidence of rot could be seen except a discoloration of the sapwood. By the end of the second or third year all of the leaves had fallen from the twigs which were exposed to the sun's rays, and the brush at the tops and sides of the piles where exposed to the sunlight had rotted to some extent, while the slash in the middle of the piles not in actual contact with the ground and yet protected from the sunlight was rotted but slightly, if at all. The twigs and small branches at the bottoms of the piles were more or less rotted by certain other fungi (called "ground" fungi in this bulletin), which apparently entered these branches from the soil. These ground fungi seem to rot the brush more rapidly and more thoroughly than the regular slash-rotting fungi.

Usually there is but little evidence of rot in the center of the piles during the first four years after piling. However, around the edges and through crevices in the top the sunlight sometimes penetrates sufficiently to permit slight fungous growth. Nevertheless, there is a marked difference between the rotting of the brush in the center of the piles not adjacent to the ground and that at the top and bottom of the pile.

By the end of five years the top and bottom of the piles have rotted to a considerable extent, while the brush in the center of the piles, where it had become more or less exposed to the sun's rays, was beginning to rot.

For the brush in the center of the piles to rot completely it apparently (1) must be brought within range of the soil moisture by the rotting of the brush below it and by the settling of the pile, or (2) the upper portion must disintegrate sufficiently for the sun's rays to reach the center of the pile. Undoubtedly, both conditions finally develop and aid in the rotting of the brush which was originally in the center of the piles.

In a white-oak brush pile the layer of brush at the bottom would be the only one even in partial contact with the soil, while the remainder of the pile would be held from the soil by this first layer and therefore could not receive any benefit from the soil moisture. Neither are the piles dense or compact enough to raise the moisture content of the air around the brush in the piles sufficiently to encourage the growth of the ground fungi in branches not in actual contact with the soil. On the other hand, the brush not in contact with the soil in the piles and yet sheltered from sunlight is deprived of the activity of the fungi which normally rot slash in the open; that is, slash when left as it falls in the tree tops.

Since piles more than five years old were not found, the writer can not state positively the length of time necessary for a medium-sized compact brush pile of white oak to rot completely. Apparently it would take from three to six years longer than if the brush were either pulled or scattered. However, if the piles are very small, the brush will rot with about the same rapidity as when the tops are left unlopped, since the sunlight can then penetrate to the bottom.

SPOROPHORE DEVELOPMENT ON PILED BRUSH.

The difference between the development of sporophores at the top, middle, and bottom of brush piles is very marked. Practically every twig and limb at the top of the pile bore the characteristic sporophores of *Stereum rameale*, *S. umbrinum*, and *S. versiforme* on the rotting limbs, while no sporophores whatever were found on branches in the center of brush piles which were large and compact enough to exclude the sunlight. Very rarely were any sporophores of wood-rotting fungi found on the material at the bottom of the piles, although sterile mycelium was frequently present on the brush so situated. It was therefore difficult to determine what fungi were concerned in the rotting of the brush in the bottom of the piles. However, sporophores were found of *Merulius tremellosus*, *Peniophora flavido-alba*, *Odontia* sp., *Poria pulchella*, and two unidentified species of *Poria*.

BRUSH WHEN SCATTERED.

When the brush is lopped and scattered it rots much more quickly than when piled, and in some localities somewhat more quickly than when left attached to the tops. On the areas examined the gain in the rotting of brush when scattered compared to that when pulled was usually about one year.

When white-oak brush is scattered, only small portions of the limbs are actually in contact with the soil. The same fungi, therefore, that rot the unlopped brush will also rot most of the scattered brush, and with about the same rapidity.

Brush lying on the ground sometimes absorbs from the soil sufficient moisture for the growth of ground fungi in those portions of the limbs which are in actual contact with the soil. On many of the areas examined the additional moisture obtained from the soil by the scattered brush was not sufficient to cause the ground fungi to attack the prostrate limbs.

The influence of soil moisture on the branches lying on the ground usually does not extend more than 4 to 6 inches from the point where the limb is in contact with the soil. This means that the benefit to be derived from the ground fungi rotting a branch is limited to that portion directly in contact with the soil. On account of the small quan-

tity of the brush thus situated, little of it is attacked by the ground fungi, and the benefits thereby derived are correspondingly slight.

At the end of five to six years all of the brush (twigs and small branches) which was scattered will have rotted, and much of it will have disappeared. It was also no uncommon thing to find partially rotted brush, whether piled, scattered, or lopped, attacked by white ants (termites) and the partially rotted wood replaced to some extent by dirt.

BLACK-OAK AND POST-OAK SLASH.

Black-oak and post-oak slash was attacked by practically the same fungi which rot the white oak; however, but little of this type of slash was seen. The twigs and small branches of the black oak in most of the cases examined seemed to rot somewhat more slowly than white-oak slash of the same character, while the post-oak slash seemed to rot with about the same rapidity as the white oak.

Polyporus cinnabarinus was occasionally found rotting the large limbs and boles of the black oak, while the small twigs and limbs of the post-oak slash were sometimes attacked by *Schizophyllum commune*, and cull logs and stumps were occasionally attacked by *Lentinus lecomtei*. *Stereum ochraceo-flavum* was the principal fungus found rotting fire-killed oak bushes 2 inches or less in diameter, while *Polystictus pergamenus* was the fungus usually found attacking fire-killed trees and fire-killed areas on standing living trees of all species of oak.

SHORTLEAF-PINE SLASH.

Shortleaf-pine slash was examined on areas which had been logged from two to nine years.

FUNGI WHICH ROT THE SLASH.

Two main fungi were found rotting the shortleaf-pine slash. One begins work in the ends of the small branches and works downward toward the trunk. This is usually *Lenzites sepiaria*, a dry-rot organism prevalent throughout the United States. This fungus has never been found by the writer attacking slash which was not exposed to the direct rays of the sun.

The second fungus enters the cull logs, boles of the tree tops, and branches 2 inches or more in diameter. It is what the writer previously has called the "white-fir fungus" (*Polystictus abietinus*).¹ It is a sap-rotting organism and usually rots but little, if any, of the heartwood.

¹ Long, W. H. A new aspect of brush disposal in Arizona and New Mexico. In Proc. Soc. Amer. Foresters, v. 10, no. 4, p. 383-398. 1915.

At the bottom of brush piles a fungus which has been identified as *Polyporus amorphus* was rather common. It apparently does not attack branches and limbs which are not in contact with the soil.

Merulius ambiguus was occasionally found on small branches, while *Fomes annosus*, *Poria subacida*, and *P. vaporaria* were found on large prostrate limbs, trunks, and stumps. *Polyporus palustris*, *Fomes annosus*, and *Corticium galactinum* seem to be the principal fungi rotting the pine stumps.

BRUSH WHEN PULLED.

All of the needles in the tops of felled shortleaf-pine trees will fall in from one to three years, depending somewhat on the locality in which the timber is located. The branches will gradually rot, and many of them will have fallen from the trunk at the end of three to four years. By the end of five years practically all of the branches, large and small, in the tops will have rotted and fallen to the ground. Also, most of the sapwood in the boles and cull logs will have rotted in this time.

Pitchy limbs and trunks containing much resin rot very slowly and may be found long after the less resinous wood has disappeared.

Polystictus abietinus and *Lenzites sepiaria* seem to rot branches which are 8 to 10 feet from the ground just as rapidly as those near the ground. *Lenzites sepiaria* also attacks decorticated logs and the exposed portions of railroad ties after they are laid in the track.

BRUSH WHEN PILED.

Shortleaf-pine brush piles were examined, ranging from 1 to 5 years in age. It was found that during the first year after the tree was cut but little rotting occurred, even in the small branches. By the end of the second or third year practically all of the needles had fallen from the limbs which were exposed to the sun's rays, while the needles in the middle of the piles, which were protected by the overlying brush, were in good condition and still attached to the limbs. In five years, brush at the top of the piles had practically rotted as far as the fungi which were attacking them could rot it, while the brush in the middle of the piles showed few signs, if any, of rotting. In the bottom of the piles the brush was well rotted, but by fungi different from those rotting the brush at the top of the piles. In other words, a brush pile of shortleaf pine will be rotted at the top by *Lenzites sepiaria* and *Polystictus abietinus*, the center of the pile will be rotted but little, while the brush at the bottom of the pile in contact with the soil will be rotted by certain ground fungi, one of which has been identified as *Polyporus amorphus*. This means that before the center of the brush piles will rot, both the top and

bottom of the piles must disintegrate sufficiently to expose the center of the pile either to the sunlight or to the moisture of the soil. This would probably add from three to five years at least to the length of time it would take to rot the slash in the brush pile as compared to that required if pulled or scattered.

BRUSH WHEN SCATTERED.

Practically the same conditions hold for shortleaf-pine slash when lopped and scattered as for oak slash; that is, the same groups of fungi which attack the pulled pine slash will attack the slash when scattered on the ground unless it be covered with leaf débris. Ground fungi will also attack that portion of the brush immediately in contact with the soil, provided the area under consideration is not too dry, like the south and southeast slopes of steep hillsides. In such locations no evidence was found of ground fungi attacking the scattered brush, or even the brush in the bottom of the piles. This means that the pine brush when lopped and scattered will rot much quicker than when it is piled, and on some sites slightly quicker than when left attached to the tops or pulled.

THE GROWTH OF WOOD-ROTTING FUNGI.

There is this physical factor to be kept in mind when considering the rotting of slash, viz, that the quantity of water which a limb or branch obtains is practically limited to the precipitation which that limb or branch receives and is able to absorb through its bark into the sapwood and that, so far as the amount of moisture in the wood itself is concerned, the humidity of the air around the branch would not be an important factor, since conditions would have to be very unique which would enable a branch covered with bark to absorb from the surrounding air a sufficient quantity of water to make any appreciable difference in the water content of the branch or limb. This would mean that the distance the branch was from the ground, whether 1 foot or 5 feet, would make but little difference in the relative supply of moisture obtainable from the atmosphere which the wood-rotting fungi in the branch could utilize. It might, however, determine to a slight extent the amount of moisture which the limbs could lose, especially in the bottoms of the piles. In regions of heavy dews the brush lying within 1 or 2 feet of the ground might obtain more moisture than brush farther from the ground.

This indicates that the slash would have to be practically in contact with the soil to gain any appreciable quantity of moisture other than that obtained from precipitation, and from the very nature of the oak brush only small portions of any given limb would be thus placed.

Different groups of fungi seem to have adapted themselves to certain growth conditions. For instance, *Stereum rameale* and *S. hirsutum* were usually found only on the twigs and small branches, while *S. umbrinum* and *S. versiforme* occurred mainly on twigs and branches 2 inches or less in diameter. None of these four fungi were found attacking large limbs and trunks of the felled trees, while *S. fasciatum*, very common on stumps and trunks, rarely occurred on branches less than 3 inches in diameter. None of them were found growing on timber which was entirely shaded from the sun.

The fungi which rot that portion of the branches lying in actual contact with the ground under the brush piles belong to an entirely different group. Such fungi apparently need a large supply of moisture and probably enter the wood from mycelia already growing and ramifying in the leaf debris in the soil. This group of fungi includes those which are normally found attacking wood partially or entirely buried in the soil, such as stumps and posts.

WHY BRUSH IN THE CENTER OF THE PILE DOES NOT ROT.

Why the fungi which are found attacking the limbs exposed to the sunlight will not usually attack the brush in the center or bottom of the piles when protected from the sun's rays is not known. Apparently temperature and moisture are not the only prominent factors controlling fungous growth and activity in nature. Is it possible that sunlight is a factor in the germination and growth of wood-rotting fungi in their natural habitats?

In a previous article by the writer,¹ the theory was advanced that the reason why the brush in the center and bottoms of the piles in the semiarid regions of Arizona and New Mexico did not rot was due to temperature conditions prevailing in the high altitudes. That the temperature in Arkansas could be a prominent factor in the rotting of the brush, or, rather, in the lack of the rotting of the brush in the middle of the piles, seems hardly possible, since the temperature there is sufficiently high during a large portion of the year for fungous mycelia to grow vigorously, provided the other factors necessary for fungous growth are also present.

The precipitation in Arkansas is sufficient to supply all the moisture necessary throughout the entire brush pile for the active growth of wood-rotting fungi. It seems, therefore, that enough moisture would persist in the center of the piles for the brush to rot at least as rapidly as the pulled brush. The fact that twigs and branches in the center of piles large enough to be shaded from the rays of the sun were the only ones not rotted seems to indicate that sunlight may possibly play a part in the rotting of the brush, not only in Arkansas,

¹ Long, W. H. Op. cit., p. 395-396.

but also in Arizona and New Mexico, where the same conditions as to the rotting of the limbs in the center of the piles were found to exist.¹

It is very evident that certain groups of fungi capable of rotting the small twigs and branches of trees which have died in the forest or of trees which have been felled are not capable of thriving under the conditions found in the center of large and compact brush piles. This is further accentuated by the fact that the bottoms of the brush piles in Arkansas, when rotted at all, are not rotted by these fungi, but are attacked by other fungi, such as *Fomes annosus*, which are known to live in more or less shaded and underground habitats.

What the factors are that dominate the growth and activity of these various groups of fungi is not known. For instance, why is it that usually *Stereum rameale* and *S. hirsutum* rarely attack limbs above 1 inch in diameter, while *S. umbrinum* and *S. versiforme* are rarely found in limbs larger than 2 or 3 inches in diameter? Why do not these fungi usually attack logs and large branches? Is the moisture content too high or the temperature too low? On the other hand, *Stereum fasciatum*, the common fungus rotting the cull logs and boles of the oak slash, usually does not attack the twigs and small branches. Of course, the explanation for this fungus might be that the twigs and small branches have not a sufficient amount of moisture, but such an explanation could not be offered for the failure of *Stereum rameale*, *S. versiforme*, and *S. umbrinum* to attack the large branches and trunks.

It would seem that but little is known concerning the real factors controlling fungous activity in wood. It is evident, however, that certain groups of fungi are capable of rotting the wood as it is normally found in nature; that is, when a tree dies, is killed by lightning, or is wind thrown. These are conditions which have been occurring in nature through centuries, and certain fungi have adapted themselves to such conditions. The same could be said of limbs and logs which are in contact with the soil, or even buried in the soil, since such conditions are normal and found generally in nature.

Apparently there are no fungi capable of vigorous growth under the artificial environments found in the center of large brush piles, where the conditions do not approximate those existing either when the brush is in contact with the soil or when it is exposed to the sunlight.

GENERAL DISCUSSION.

Several factors, such as fire, reproduction, and the rotting of the brush, are so intimately associated that it is impossible to discuss any one phase of brush disposal without noting, at least briefly, the

¹ Long, W. H. Op. cit., p. 389-390.

possible influence of these other factors. It is obviously impossible to arrive at any legitimate conclusion concerning the best method of brush disposal by limiting the discussion to the pathological side of the question as seen in the rotting of the brush itself. The fire hazard, as it seems to exist in Arkansas, is therefore briefly discussed in connection with brush disposal from the pathological viewpoint.

In the Arkansas National Forest about 3 to 5 white-oak trees are felled to the acre, and about 5 to 10 pine trees to the acre. In the Ozark National Forest the proportion of white-oak trees felled is somewhat greater, running probably from 5 to 10 trees to the acre, while there is but very little pine cut on this forest. This means that on any area in either of these two National Forests where timber is being cut, especially white oak, a much greater percentage of standing trees of all sizes, including those below the merchantable diameter limit, is left than is cut. This standing timber will add its annual quota of fallen leaves to the ground cover, irrespective of what method of brush disposal is followed. The amount of litter in the shape of slash, on account of the small number of trees cut per acre, in many cases will not make fires more likely to start or prevent their control, since there will always be a sufficient quantity of leaf litter and underbrush present to make a good ground fire, even if there be no slash on the ground. If the deciduous trees are cut with the leaves on them the amount of leaf litter will not be increased, since these leaves would fall to the ground in the autumn even if the trees were not cut; in fact, there would really be less leaf litter on the ground, because the leaves persist on the felled tree tops and branches from one to three years.

There is also this fact to be borne in mind, that oak trees cut from November to March, inclusive, are leafless or practically so, and the brush from them will not materially increase the fire hazard unless it is piled.

In 1912 and 1913 the writer visited areas in the Ozark National Forest which were then being logged. In the studies made in 1915, only two to three years later, many of these areas had been burned over. It can probably be said truthfully that the greater portion of the Ozark National Forest, except about 100,000 acres in the middle of the central division, will be burned over at least once within a period of five years, and often within a much shorter interval. It seems, therefore, that whatever system of brush disposal is followed in this forest should take into consideration the certainty of fire as well as the rotting of the brush.

In the Arkansas National Forest many areas are not burned over more than once in every 20 years. Under such conditions the rotting of the brush is the main factor to be considered.

No areas were seen on which brush had been cut and scattered where there had been fire. What effect, therefore, a fire would have on such areas as compared with those on which brush had been piled or pulled can not be stated from actual observation. However, areas were seen on which there had been fires where brush had either been pulled or piled. Many trees whose tops had been left with the limbs unlopped were seen with the needles or leaves burned from only the lower half of the tops. This leaving unburned the leaves and needles in the upper half of the felled tree tops seemed to indicate that fires in the forests of Arkansas in pulled brush do but little, if any, more damage than the regular ground fire which is fed by the normal annual leaf débris and underbrush. Many areas on which the brush had been piled were seen where forest fires had killed a large portion of the young reproduction up to 4 inches in diameter.

Brush when lopped and piled rots much more slowly than under either of the other methods of disposal. Such piles may be expected to persist from three to six years longer than the same brush when pulled or scattered, depending upon the size and compactness of the piles. This would eliminate the large brush piles from consideration in disposing of the slash on these areas.

The best method of brush disposal over such areas would be that which is the least expensive, which reduces to a minimum the damage to the forest when fires occur, and which leaves the slash in such condition that it will rot most rapidly. It is very evident in view of these three things that the lopping and piling of the brush is the poorest method to follow, since not only is it the most expensive, but brush when piled rots the slowest and the reproduction on such areas is apparently damaged most by forest fires, judging from the burned areas seen. This would leave the choice between scattering and pulling.

Pulling, as practiced in coniferous timber, would not be practicable in certain types of hardwood sales, such as stave sales, since the oak tops are usually too heavy to be moved as a whole by the methods of logging in use on such areas. However, when tree tops fall near reproduction or near trees to be left, it is immaterial whether the top is pulled away by a team or by hand or whether the objectionable sections of the top are sawed out and rolled away.

Brush when pulled or left in the tops rots with nearly the same rapidity as when lopped and scattered. The difference in time between the rotting of the pulled and of the scattered brush is apparently about one year in favor of the scattered brush. Whether a possible maximum gain of one year in the time of rotting between the brush that is pulled and that which is scattered is sufficient to offset the difference in cost between these two methods must, of course, be considered.

SUMMARY.

(1) When the brush is lopped and scattered it rots more rapidly than when either piled or pulled. This is due to the fact that two types of fungi rot the brush, one entering the limbs and branches not in direct contact with the ground and the other entering those portions of the brush in actual contact with the soil.

(2) The maximum gain in the rapidity of the rotting of the brush when scattered over the same brush when left unlopped in the tree tops is about one year. On dry areas, such as steep hillsides with southern and western exposures, there is practically no difference in the rate of rotting of the brush when scattered and when the tree tops are left unlopped.

(3) Brush when lopped and piled will apparently take from three to six years longer to rot than when scattered or when left unlopped.

(4) Brush when piled is rotted at the top by one group of fungi and at the bottom by another group, while the middle of the pile, not in contact with the soil and yet protected from the sunlight, apparently will not rot to any extent until the pile disintegrates sufficiently to expose these central layers to the soil moisture on the one hand or to the sunlight on the other.

(5) The same general facts as to the rotting of the slash hold for all species of timber (pine, oak, etc.) examined in Arkansas.

(6) Four fungi are the main agents in the rotting of oak slash in Arkansas, viz, *Stereum rameale*, *S. umbrinum*, *S. versiforme*, and *S. fasciatum*.

(7) Two main fungi rot the shortleaf-pine slash, viz, *Polystictus abietinus* and *Lenzites sepiaria*.

(8) No definite conclusions could be reached concerning the principal fungi which rot the bottom of the piles, since but few sporophores of such fungi were found.

(9) None of the main fungi concerned in rotting either the oak or the pine slash in Arkansas produce heart rots in living trees.

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UNITED STATES DEPARTMENT OF AGRICULTURE



BULLETIN No. 510

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief



Washington, D. C.

PROFESSIONAL PAPER

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TIMBER STORAGE CONDITIONS IN THE EASTERN AND SOUTHERN STATES WITH REFERENCE TO DECAY PROBLEMS.

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(In cooperation with the Forest Products Laboratory of the United States Forest Service, Madison, Wis.)

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INTRODUCTION.

During the past few years a large number of requests for information on the control of decay in building and factory timbers have reached the United States Department of Agriculture. In many instances the cases reported have involved serious losses, often running into the thousands of dollars.

The rapidly rising interest in the question on the part of the public may be attributed to two general causes: (1) The greater publicity being given to this work in the Department of Agriculture, particularly through the activities of the Office of Investigations in Forest Pathology of the Bureau of Plant Industry and the Forest Products Laboratory of the Forest Service, and (2) the increasing use of timber less resistant to decay, which has become very marked during the past decade.

As a preliminary to an investigation into the prevalence of decay in building timbers, with the prime object of securing some basis for

the effective control of such losses, a field study covering about seven months' active work was undertaken during 1914 to determine the conditions under which lumber and structural timbers are stored, for it is a well-known fact that timber infected with wood-destroying fungi during storage may be the direct cause of outbreaks of rot in buildings when such timber is placed in situations favorable to decay.

On account of the many failures in timber in important structures during recent years,¹ such an investigation is of the highest importance, both from the standpoint of owners and contractors and from that of the timber interests themselves.

The writer has encountered a number of instances where he was informed that wood has been replaced by steel or concrete for no other reason than the failure of locally available timber to withstand decay. An increasing use of these structural materials is bound to occur unless the lumber industry takes steps to improve the quality of its product for the North American market, and the first step in this process of regeneration lies in the better sanitation of lumber storage yards, so as to remove the danger of directly transferring fungous infections from the lumber dealer to the consumer.

During the course of this study a large number of sawmills and wholesale and retail lumberyards were visited in the eastern half of the United States. The region comprised 10 States along the Atlantic coast from Maine to Florida, all of the Gulf States, and the Central States of Arkansas, Iowa, Illinois, and Wisconsin. In addition to a personal inspection of the yards, much valuable information was obtained directly from the operators.

CAUSE OF DECAY IN TIMBER.

Decay in timber is almost exclusively due to the action of fungi, the greater part of the destruction being referable to one of the higher groups of these organisms, namely, the Hymenomycetes. In the life cycle of these fungi there are two distinct phases of development: (1) The vegetative stage (mycelium) and (2) the fruiting stage.

MYCELIUM.

The mycelium consists of microscopic threadlike filaments, usually branched, which penetrate the wood either by traversing the natural longitudinal passages, such as the pores, resin canals, or cell cavities, or by passing through the walls or through the pits in the walls of the wood fibers or tracheids (Pl. I, fig. 1). The mycelium also invades the pith rays, which contain a great abundance of food mate-

¹ In this connection, see the report by F. J. Hoxie, entitled "Dry Rot in Factory Timbers," 34 p., 19 fig., Boston, 1915, published by the Inspection Department of the Associated Factory Mutual Fire Insurance Companies, Boston, Mass.

rials readily available to the fungus and whose walls are thinner than those of the wood fibers and hence more readily penetrated.

The growth of the mycelium is conditioned by four factors: (1) The presence of satisfactory food supplies, (2) a suitable amount of moisture in the wood, (3) a temperature favorable for growth, and (4) at least a small supply of air to furnish the necessary oxygen.

Food supplies.—The mycelium, being a living, growing plant, must have nourishment for growth, and so utilizes for this purpose various constituents of the wood substance. These consist of the different compounds which go to make up wood tissue, the celluloses and ligno-celluloses being utilized as well as sugars, starches, and certain organic acids. To break down the woody tissues, which are chemically very complex, and thus render them assimilable to the fungus, certain imperfectly understood chemical substances (enzymes or ferments) are secreted by the organism. These act upon the wood substance, reducing it to simpler nutritive compounds. A number of these ferments have been isolated and studied by various investigators and their physiological and chemical action determined. They are quite specific in their action; different substances which enter into the composition of wood require different ferments to disorganize them. In general, however, the wood-destroying fungi are well supplied with the ferments necessary to produce serious disintegration of most of the constituents of woody tissues.

Moisture.—A considerable amount of moisture is necessary for rapid decay. Timber in an air-dry condition during dry weather will not ordinarily be affected, but during periods of rainy weather, when the atmospheric humidity is high, fungous infections may become serious. In highly humid stagnant air a surface development of mycelium (Pl. I, fig. 2) is possible, but under conditions of free air circulation the surface is usually kept too dry for this to occur, although the interior of large timbers may still retain sufficient moisture for decay to progress within them.

Temperature.—Wood-destroying fungi can maintain themselves over rather wide ranges of temperature, but have an optimum for most rapid development within comparatively narrow limits. According to German investigations *Merulius lachrymans* (Wulf.) Fr. has an optimum between 65° and 72° F. (18° and 22° C.); *Coniophora cerebella* (Pers.) Schröt. (= *C. puteana* (Schum.) Fr.) between 72° and 79° F. (22° and 26° C.), and *Lenzites sepiaria* (Wulf.) Fr. between 82° and 90° F. (28° and 32° C.).

Growth below these points is often considerably retarded, while a rise of 4 to 8 degrees above the optimum often causes total inhibition of growth or even death, as in the case of *Merulius lachrymans*, which is very sensitive to temperature changes above the optimum.

Air.—Under ordinary conditions the air supply within and surrounding the timber is amply sufficient for decay. Fungi develop best in still air in closed spaces, but this is due to the greater humidity rather than to air requirements, for a good air circulation dries the timber to a point unfavorable to the development of the organisms.

In the case of timber thoroughly saturated with water, however, so that the cell cavities are filled with the liquid, decay is prevented entirely through lack of sufficient oxygen.

FRUITING BODIES.

Fruiting bodies are an expression of fungous activity within the wood. They form only after decay has well started. They appear at the surface in the form of single or imbricate shelves or brackets, leathery or waxy incrustations, or, in a few cases, as mushrooms (Pl. I, fig. 3) with central or eccentric stems bearing an expanded cap at the top.

The fruit bodies of the many fungi which cause decay in timber may vary in color from white through reds and yellows to dark brown or blackish. The consistency or texture is also highly variable, from fleshy to tough and leathery, and occasionally hard and woody. In some species the under side, or outer surface where the fungus is spread out as a crust (resupinate), is smooth (*Stereum*, *Corticium*, *Peniophora*, *Coniophora* (frequently warted)). In other cases, the under side, or the outer surface where resupinate, bears numerous pores (*Polyporus*, *Poria* (Pl. II, fig. 5), *Merulius*, *Trametes*, *Daedalea*, *Fomes*). Still other species have platelike gills on the under side (*Schizophyllum*, *Lentinus*, *Lenzites*). Occasionally, forms with distinct spines (Pl. I, fig. 4) or teeth are encountered (*Hydnum*). Various other species are illustrated in Plates III to X.

HOW WOOD-DESTROYING FUNGI SPREAD.

There are two general methods by which wood-destroying fungi spread from infected to sound timber: (1) By a direct overgrowth of mycelium from an infected stick to adjoining or near-by timber, and (2) by the blowing about of spores produced by the fruit bodies or by the mycelium.

Infections by mycelium.—In wholly or partially inclosed moist spaces, such as are often found in the basements of buildings, in mines, or beneath low, poorly ventilated lumber piles, the mycelium finds sufficient moisture in the air to allow it to develop on the surface of timbers, and in this way may progress along the timber for considerable distances. Such may be the case also where timber is close piled; the writer has records where severe infections have

thus passed during rainy weather from the bottom upward through piles 12 to 15 feet high. In lumber storage sheds or in the base of close piles the mycelium of several species of fungi has frequently been observed developing in great abundance, not alone on the moist foundations and lower layers of lumber (Pl. II, fig. 1), but also spreading profusely on the soil (Pl. II, figs. 2 and 3).

With some species of wood-destroying fungi the mycelium within infected timber may remain alive for long periods, even under air-dry conditions, a fact which makes the use of infected timber in building operations a dangerous procedure. As an example, we have the experimental evidence advanced by Bayliss¹ that the mycelium of *Polystictus versicolor* in wood can survive a period of four years under the dry conditions of a herbarium.

Infections by spores.—The chief purpose of spore formation in fungi, just as in seed formation in ordinary green plants, is the perpetuation of the species through reproduction. Spores serve the two-fold purpose of tiding the fungus over unfavorable periods and of allowing its rapid spread under favorable growth conditions. Nature is lavish in her methods, and the number of spores produced is often enormous. For instance, Buller² computed from partial counts that each pore on the under side of *Polyporus squamosus* produced in the course of a few hours an average of 1,700,000 spores, or a total of over eleven billion for the entire under surface of a fruit body having an area of 250 square centimeters (38.75 sq. in.). When one recalls that spores are either constantly or intermittently produced by a single fruit body over a long period the further statement made by Buller that "the number of spores produced by a single fungus * * * in the course of a year may, therefore, be some fifty times the population of the globe" becomes intelligible.

At least two general types of spores are recognized for most wood-destroying fungi, the most easily observed being the basidiospores produced by the fruit bodies. These may frequently be seen en masse as a white or colored powdery deposit which has fallen from the sporophores (Pl. II, fig. 4). These spores are produced on short stalks at the ends of club-shaped cells which form a palisade layer (Pl. II, fig. 6) covering the under surface of the fruit body, or, in case the fruit body is of the incrusting type, covering its outer surface. When mature, the spores are cast off the basidia into the air and are blown about by the wind. When they lodge in a moist place favorable for growth they readily germinate and produce a new infection.

¹ Bayliss, Jessie S. The biology of *Polystictus versicolor* (Fries). In Jour. Econ. Biol., v. 3, no. 1, p. 1-24, 2 pl. 1908.

² Buller, A. H. R. The biology of *Polyporus squamosus* Huds., a timber-destroying fungus. In Jour. Econ. Biol., v. 1, no. 3, p. 101-138, illus., pl. 5-19. 1906.

Both the fruit bodies and basidiospores vary greatly in vitality among the different species of fungi. External temperature and moisture conditions exert a great influence, particularly when the two are working together in an unfavorable rôle.

Low temperatures appear far less injurious than high temperatures. Buller and Cameron¹ report gathering living fruit bodies of *Schizophyllum commune* from a woodpile at Winnipeg, Canada, in March at a temperature of -17° C. (1° F.), after exposure for several months at winter temperatures ranging between -15° and -40° C. (5° and -40° F.). After thawing for a few hours the fruit bodies cast spores readily. They further report that immersing an active fruit body of the same fungus in water and placing it in the open over night at a minimum temperature of -31° C. (-24° F.) did not suffice to kill the organism, although it was frozen into a solid block of ice.

Carrying the work still farther, Buller² exposed fruit bodies of the same fungus (previously kept dry for two years and eight months in ordinary air) to the temperature of liquid air, -190° C. (-310° F.), for three weeks in a vacuum tube. Upon removal and moistening, the fruit bodies were still alive and cast spores in abundance.

In his larger work³ and certain later articles, the same author shows that at ordinary temperatures dried fruit bodies retain their capacity to produce spores for long periods; for instance, *Daedalea unicolor* can remain alive in the dark at least $8\frac{1}{4}$ years and *Schizophyllum commune* at least $6\frac{1}{4}$ years. Certain others may retain their vitality for only two or three years.

In the case of temperatures above the optimum, however, the injurious effect may become marked within a comparatively small range. For instance, Falck⁴ states that fruit bodies of *Lenzites abietina* fail to produce spores after five days at 26° (78° F.) and the spores fail to germinate at 42° C. (108° F.). A corresponding relation is also said to exist with *Merulius lachrymans* and other species, for the same author⁵ states that fresh fruit bodies of *Merulius domesticus* (= *M. lachrymans* in part) are killed in 30 minutes at 40° to 42° (104° to 108° F.) and in 15 minutes at 46° C. (115° F.); at 42° C. (108° F.) dry spores are killed in 12 to 16 hours.

In addition to spores produced in fruit bodies, another set of reproductive bodies is often produced directly by the mycelium.

¹ Buller, A. H. R., and Cameron, A. T. On the temporary suspension of vitality in the fruit bodies of certain Hymenomycetes. In Proc. and Trans. Roy. Soc. Canada, s. 3, v. 6, 1912, sec. 4, p. 73-78. 1913.

² Buller, A. H. R. Upon the retention of vitality by dried fruit bodies of certain Hymenomycetes, including an account of an experiment with liquid air. In Brit. Mycol. Soc. Trans., v. 4, 1912, pt. 1, p. 106-112. 1913.

³ Buller, A. H. R. Researches on Fungi . . . 287 p., illus., 5 fold. pl. London, 1909.

⁴ Falck, Richard. Die Lenzites-Fäule des Coniferenholzes. In Möller, Alfred. Hauschwammforschungen. Heft 3, p. 69 and 98. 1909.

⁵ Falck, Richard. Die Merulius-Fäule des Bauholzes. In Möller, Alfred. Hauschwammforschungen. Heft 6, p. 339. 1912.

These bodies may be borne on short stalks on the mycelial threads (conidia), or the mycelium itself may break up into short cells (oidia), or specialized thick-walled cells (chlamydo-spores) may form within the mycelium. The last kind of spore, on account of its thicker wall, is adapted to withstand unfavorable weather conditions; the two former kinds are usually thin walled, minute, and readily blown about by the wind.

With these fundamental facts in mind, let us now turn to a discussion of the present conditions under which timber is stored and see wherein these conditions contravene the known facts regarding the development and spread of decay-producing fungi.

HANDLING TIMBER AT SAWMILLS.

The practice at different sawmills varies widely. A few of the larger mills, particularly in the longleaf-pine belt, put almost their entire cut through the dry kiln and then store it under closed sheds. This practice is to be highly commended, and if the storage sheds are well drained and properly ventilated beneath, no trouble from fungi should be experienced.

However, comparatively few mills have the facilities for handling their product in this approved fashion, and the great majority have kiln capacity for only the B and better grades of lumber. The remainder of the output is piled in the open yard (fig. 1), the higher grades of lumber often being dipped in sodium bicarbonate or sodium carbonate to prevent blue stain.

Some few mills of the poorer class and smaller type dispense with both kiln drying and dipping and pile their entire green stock in the open yard. The few mills of this type which the writer has visited are usually also very lax in their methods of piling and of yard sanitation.

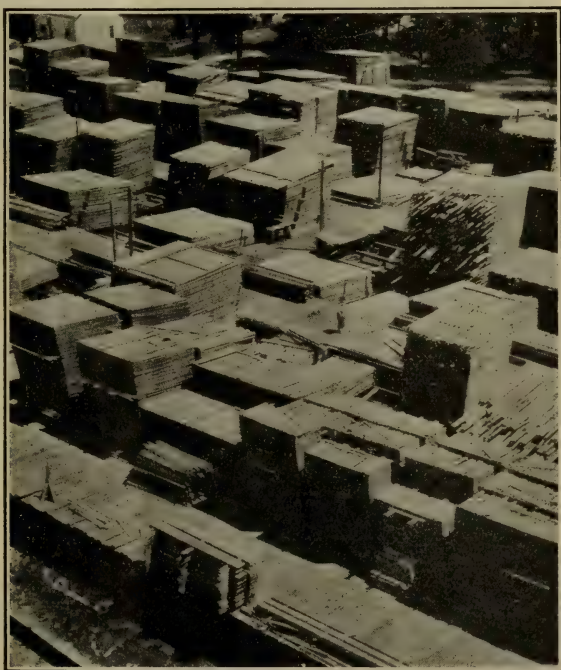


FIG. 1.—Bird's-eye view of a clean lumber-mill yard in Arkansas, showing the usual method of open storage.

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LOCATION OF MILLS AND ITS RELATION TO DECAY.

The location of sawmills is usually determined by certain economic considerations which do not readily admit of change. Many of the



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FIG. 2.—Lumber piled at the water's edge on the Atlantic coast. High waves sweep over this during storms, wetting the lumber and producing rot.

mills are located either on streams or along the low and swampy Atlantic or Gulf coasts. Very often higher dry land is not available for storage purposes and then, particularly in the South, the conditions for decay are excellent.



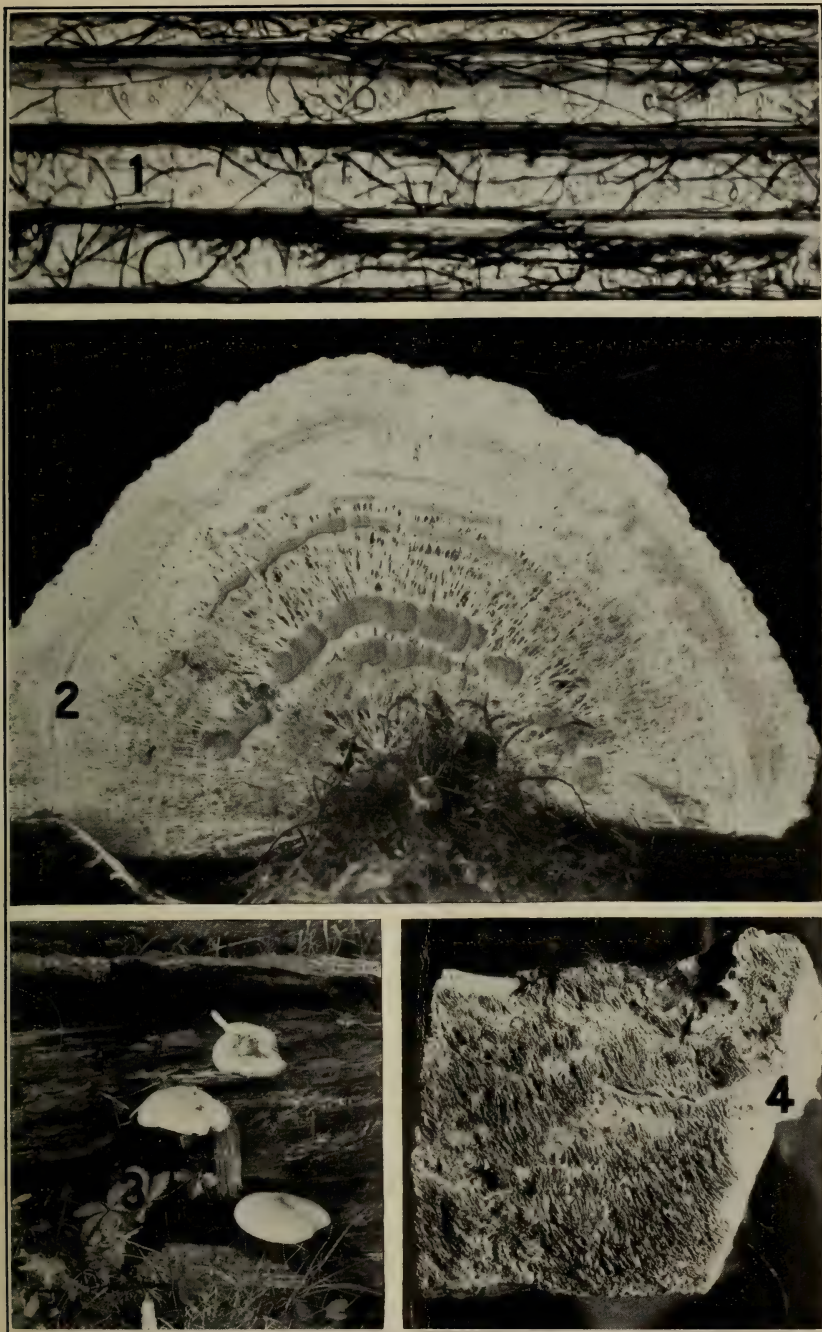
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FIG. 3.—Silt deposited in the base of a lumber stack during a Mississippi River flood. This condition permits the lumber to rot rapidly.

In some instances attempts have been made to fill in this low land with sawdust, bark debris, etc., with the result that the soil is made over into a most excellent culture medium for the development of wood-destroying fungi. In

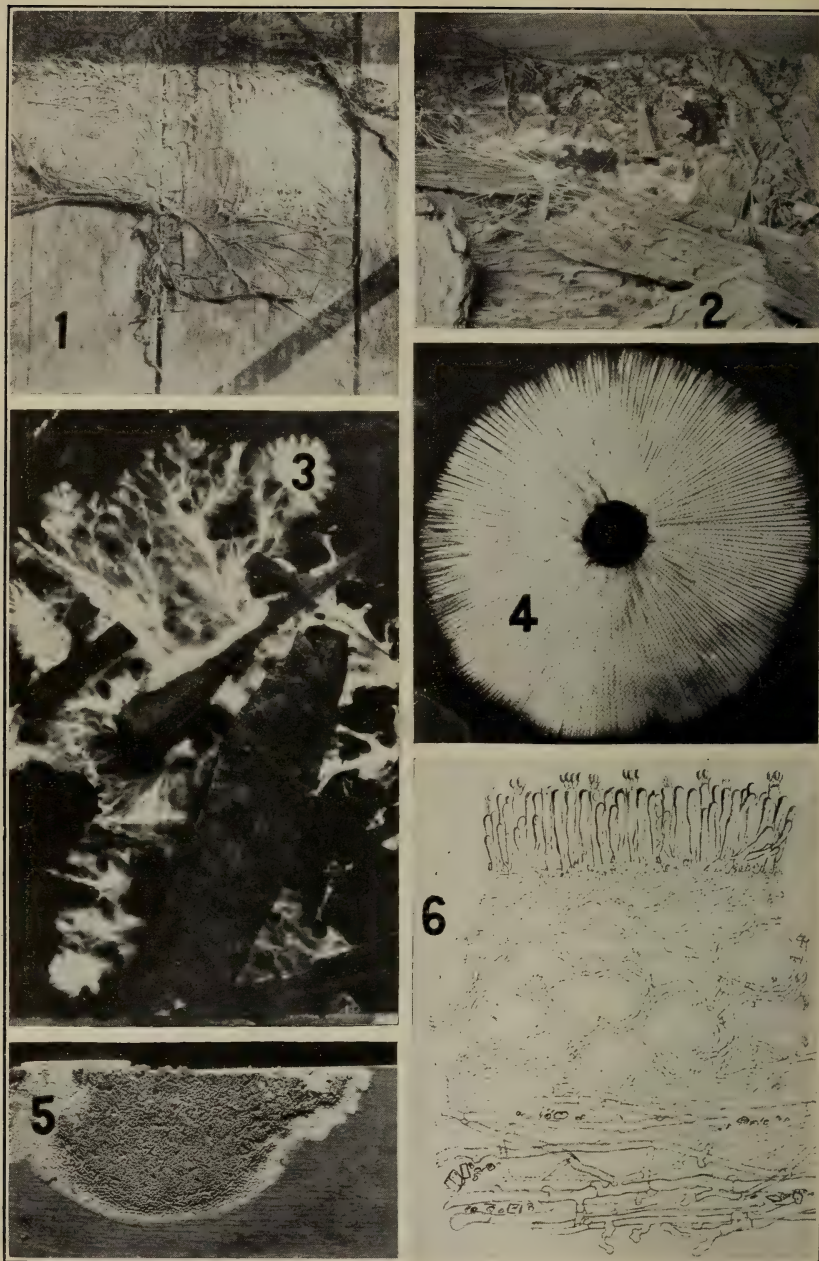
other cases yards, even when on comparatively high ground, are so graded as to allow drainage into the yard rather than away from it.

In the coastal regions, where mills are at times located just above the level of high tide, storm waves frequently beat in from the sea



LUMBER SANITATION: WOOD-ROTTING FUNGI.—I.

FIG. 1.—Thin section of "red-heart" pine, showing fungous threads and holes where these have bored through the walls of the wood cells. FIG. 2.—Mycelium on a board from a clay mine, Joplin, Mo. FIG. 3.—The mushroom *Pluteus cervinus* on a rotten log. FIG. 4.—A species of *Hydnum*.



LUMBER SANITATION: WOOD-ROTTING FUNGI.—II.

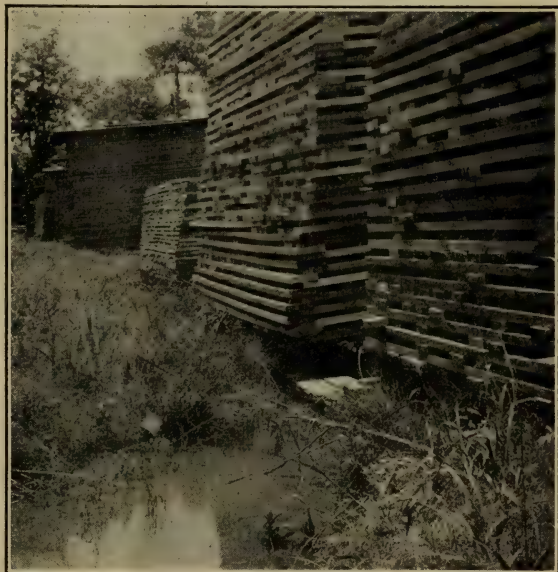
FIG. 1.—Strands of mycelium of the “dry-rot” fungus, *Merulius lacrymans*, on the face of pine planks in a lumber pile at Portland, Me. (the fungus has progressed to a height of six layers or more). FIG. 2.—The same fungus on the ground and in litter beneath an open storage shed, Philadelphia, Pa. FIG. 3.—Mycelium of a white *Poria* on the ground and on wood fragments beneath a cotton mill, Adams, Mass. FIG. 4.—Powdery deposit of spores cast by a mushroom over night (after Atkinson). FIG. 5.—A species of *Poria* from a porch ceiling, Madison, Wis. FIG. 6.—Thin section of an encrusting fruit body of *Merulius lacrymans*, showing palisade layer of basidia bearing spores (after Falck).

and sweep over the lumber, wetting it and depositing silt over great quantities of the stock (fig. 2). The writer has seen instances along the Atlantic seaboard where lumber stacks at least 12 feet high were thus silted completely to the top. A somewhat similar condition exists along certain rivers during times of flood (fig. 3).

Where it is necessary to store lumber upon low swampy ground (figs. 4 and 5), the weed problem also becomes a serious factor. In the first place the growth of vegetation is so luxuriant as to require constant attention, and in the second place the ground is not even or firm enough to allow convenient mowing. The result is that sometimes the weeds are allowed to develop above the height of the foundations, thus cutting off air circulation beneath the piles and hence increasing the danger from fungi many fold.

QUALITY OF STOCK WITH REFERENCE TO DECAY.

The fact that American mills are utilizing their timber to a smaller size than formerly throws a greater quantity of the inferior grades upon the storage yards. Rapid deterioration in this low-grade stock may result unless it be carefully handled. In the



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FIG. 4.—Lumber piled on low swampy land at a Texas sawmill. The serious decay in this yard is due to the excess of soil moisture and poor circulation beneath the stacks.

case of many yellow-pine structural timbers it is a matter of common observation that the quality is growing decidedly poor, this being in large part due to the fact that small second-growth trees are being logged and cut into dimension sizes. In the shortleaf-pine business, in particular, a single mill rarely attempts to cut both board and dimension stock. As a rule, it is said to be more profitable to cut the better grade larger shortleaf and loblolly trees into 1 and 2 inch stock. Hence, for structural sizes the trade largely depends on certain timber mills, as well as a multitude of small portable mills operating in young second-growth timber. The storage of these less

durable grades at times becomes a considerable problem, not alone at the mills but also in the retail yards. In fact, the writer has been told by certain retailers that deterioration due to decay in these low grades had become so serious with them that they had discontinued carrying such hazardous stock.

In the case of hemlock, spruces, firs, low grades of pine, and certain of the less durable hardwoods, storage difficulties are bound to develop at times during exceptionally wet seasons, but much of the

trouble can be forestalled by applying the proper methods of sanitation.

It is necessary that if such material is to enter into the construction of buildings it should be entirely free from fungus infection. Responsibility for clean lumber must rest with the lumberman.

CONDITION OF STORAGE SHEDS AT MILLS.

As noted before, many mills, including some of the larger ones, are operating

under serious disadvantages of location as far as decay is concerned. The better types of storage sheds are inclosed at the sides, with ample ventilation beneath (fig. 6), but those open on both sides are not uncommonly met with. The exclusion of water from stored lumber becomes a necessity when such material is put in close piles under cover, where the drying action of wind and sun does not have full play. This is particularly true where sheds are built over low swampy ground where the vapors on rising from the wet soil are more or less imprisoned, keeping the air at a high humidity. A little extra moisture in such cases may be sufficient to permit the outbreak and rapid spread of fungus infections.

The greatest source of danger in storage sheds lies in placing the lumber too close to the ground, and several instances have been noted



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where widespread infections of some of the worst building fungi in the country have been prevalent in the foundation timbers and stored lumber in contact with them (Pl. X, figs. 1 and 3). Many of the sheds over low ground have drainage canals beneath to carry away excess water, and in some instances, where the pitch of the ground is not sufficient, stagnant water may accumulate over long periods. This may cause high humidities, approaching saturation, which permit the white cottony mycelium of wood-destroying fungi to develop rapidly over the surface of the timber. In general, it has been the experience of the writer that moisture conditions around the foundations of storage sheds are often very favorable to decay.

Leaky roofs at times become a source of trouble. A few instances have come to the writer's attention where comparatively small leaks have caused a considerable amount of visible, material decay in the upper parts of lumber piles. However, when we realize that in many cases the infection, on account of the short time in storage, does not have the opportunity to cause marked deterioration, but still is present in an incipient stage ready to progress farther

when placed under moist conditions, we can readily see the serious consequences which may ultimately accrue.



FIG. 6.—Large storage shed at Laurel, Miss., set on concrete piers, high off the ground, with ample ventilation from all sides. This is the best type of construction.

CONDITION OF STORAGE YARDS AT MILLS.

GENERAL SANITATION.

The vital necessity, viewed from the standpoint of decay, for absolute cleanliness around lumberyards is perhaps not fully appreciated by most lumbermen. The question of fire hazard, however, has led most mills to take certain steps in this direction which are of very great importance. These steps have usually assumed the form of keeping grass and weeds down, particularly in the dry season, and of removing rotten débris to a considerable extent.

A broad survey of the lumber industry shows some instances where



P72F

FIG. 7.—A small, very insanitary mill in Louisiana. The conditions at this mill are a disgrace to the lumber industry. Note the rotten, dilapidated tramway, the lumber stacks placed within 2 to 4 inches of the ground, and the débris scattered about and breeding infection.

absolutely no attention is given to yard sanitation (fig. 7) and also a few other instances where the yards are sodded and handled like a well-kept lawn (fig. 8). The great majority, however, fall between these extremes. As a rule, grass and weeds are kept under fairly good control either by mowing or by pasturing. In most instances some rotting débris is scattered about. The factor of location often plays an important part in sanitation, for on swampy land the lessened fire danger tends to encourage carelessness.

Any decaying timber which has been allowed to accumulate about the yards should be collected and burned. The mere carting of such débris to a convenient near-by pile (Pl. III, fig. 1; text fig. 9) is not sufficient, for the fungi will continue to thrive in such material for long periods and to produce fruit bodies which will liberate millions upon millions of spores into



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FIG. 8.—The well-kept grounds of a high-class longleaf-pine mill in Louisiana. Practically all the lumber is run through the dry kiln and stored in large sheds, thus eliminating the problem of storage rots.

the air to infect whatever sound lumber may be in the vicinity. The writer has seen scores of instances where small piles of rotting débris have been scattered about lumberyards and even at times piled directly against sound lumber (fig. 10). Very frequently this débris consists of old ties (fig. 11) or timbers from the tramway platforms. In other cases it may be yard stock which has rotted in storage and has been left in situ or carted a few rods and discarded just beyond the confines of the yard. One such mill yard was visited where several hundred thousand feet of pine and hardwood lumber had been thrown into an adjoining rice swamp in close proximity to and extending for nearly a mile along a row of lumber stacks (see fig. 9). In this same yard it was also commonly noted that sound lumber fresh from the saw was piled upon the bases of old lumber piles which were thoroughly rotted (fig. 12).

Also in this yard, as well as in a yard in Mississippi, vines were allowed to grow up over some of the lumber piles (fig. 13). This is, of course, highly objectionable, since such vegetation tends to collect moisture and impedes ventilation.

Such conditions as these are bound to be a serious menace to the effective storage of lumber.



FIG. 9.—Pine and hardwood lumber which has rotted in storage in the yard shown in figure 11. Instead of burning the débris it was thrown into an adjoining rice swamp. Fungi developing on this débris will again infect the sound lumber.

TRAMWAYS AND RAILWAYS.

Practically all sawmills have a more or less extensive tramway or railway system for the distribution of lumber from the mill to the yard and other units of the plant (fig. 14). It is quite the universal condition that these structures harbor multitudes of various

wood-rotting fungi, which cast off innumerable viable spores to be carried about by air currents to sound lumber. The elevated position of these fruit bodies on high tramways gives much greater facility to the wide distribution of their spores.

Since the tramways require large amounts of timber in their construction, the use of wood preservatives in protecting them from decay is worth careful consideration. This would effect a direct saving both by prolonging the life of the timber and by preventing

the development of the fungous fruit bodies.

In only one part of the tramway structure is decay secondary to other deteriorating factors, and this is in the planking. Where the trucks or "buggies" operate constantly, the wear at the center very often nicely balances the decay at the ends, but even here, from the standpoint of sanitation alone, a light preservative treatment sufficient to immunize the timber so that fungous fruit bodies can not develop is strongly recommended.



FIG. 10.—Partially rotted hardwood boards piled against a lumber stack. Infection will spread by contact to the sound lumber.

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The initial cost of constructing extensive tramways from 10 to 25 feet high reaches a considerable figure, even at the actual mill cost of the timber. In the upkeep of these structures replacements are necessary as rapidly as the timbers fail, the resulting maintenance charges being a considerable item of expense. In none of the mills visited had thorough wood preservative treatments been applied. Partial attempts were noted in several instances, where brush treatments, usually of some patented coal-tar compound, had been applied at the joints. Ordinarily it is the more widely advertised trade products which reach the attention of millmen. The cheaper preserva-

tives appear to be little known. In the opinion of the writer, thorough preservative treatments would effect an ultimate saving in maintenance charges, a considerable part of the cost of application being offset by the use of cheaper grades of timber, which when treated properly will last longer than the highest grade of natural wood available.

In very few lumberyards are the railway ties preserved in any way. In most cases they consist of inferior timber which readily decays. Many fruit bodies of dangerous fungi are usually present (Pl. III, fig. 2), so that it is important from the standpoint of sanitation to remove this source of infection by the application of wood preservatives, such as creosote or zinc chlorid. A track in which the ties are creosoted is shown in figure 15.

FOUNDATIONS.

Probably no other factor involved in the storage of lumber in yards is open to more criticism from the sanitation standpoint than the foundations to the piles (figs. 16 and 34). Almost invariably these timbers are severely infected and often abundantly supplied with sporulating fruit bodies of serious wood-rotting fungi (Pl. III, figs. 3 and 4).

Various types of foundations are in use. The most primitive and most insanitary type consists in laying planks directly on the ground and stacking the lumber upon them. This procedure occurs at only a few of the smaller mills. A few of the mills make use of built-up plank foundations (Pl. III, fig. 3), but the more usual method is to use 6 by 8 or 8 by 10 stringers, blocked up to a height of

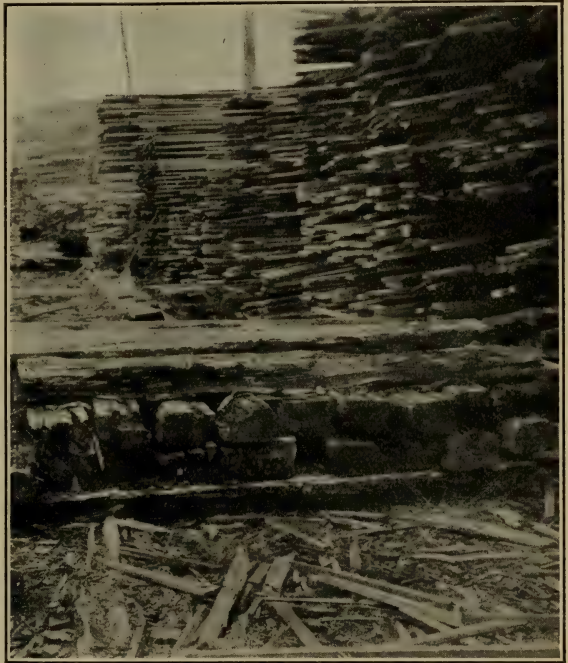
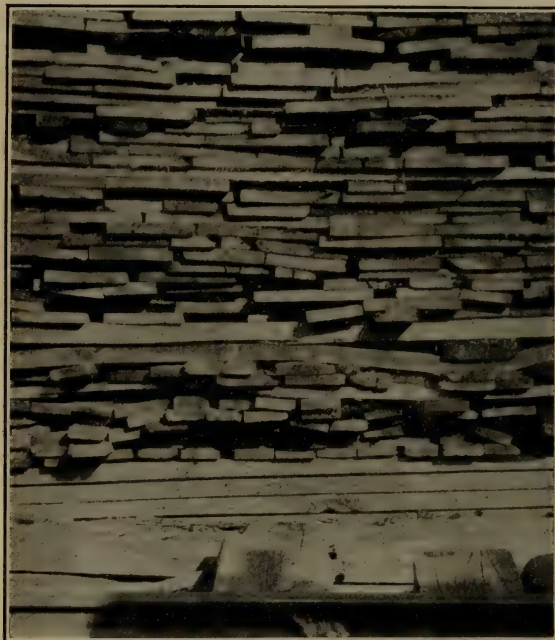


FIG. 11.—A highly insanitary mill yard in South Carolina. Hundreds of thousands of feet of stored lumber have rotted in this yard as a result of these conditions. All this rotten debris should be removed and burned.

1 to 2 feet (fig. 16) or set on short posts. A few of the best mills make use of concrete piers for this purpose. The latter type of foundation would be greatly improved by the use of stringers treated with a wood preservative.

The dangers arising from partially rotted foundations are evident, as has been seen from the earlier discussion of the activities of wood-destroying fungi. Where wood blocks are used to support the skids, fungi often progress directly from the moist soil upward, in this way frequently infecting the skids, thus adding the possibility of direct

mycelial infection to that of spore infection. The infected skids themselves are dangerous, since the fungous mycelium can progress directly from them to the bottom of the lumber piles (Pl. IV, fig. 3; text fig. 17). Once started, and the weather conditions being warm and moist, such infections may pass through an entire stack. In considering the menace of infected skids, we must also not lose sight of the fact that such timbers are a prolific source of fruit bodies (Pl. III, fig. 3) with their many spores, to be borne up into the

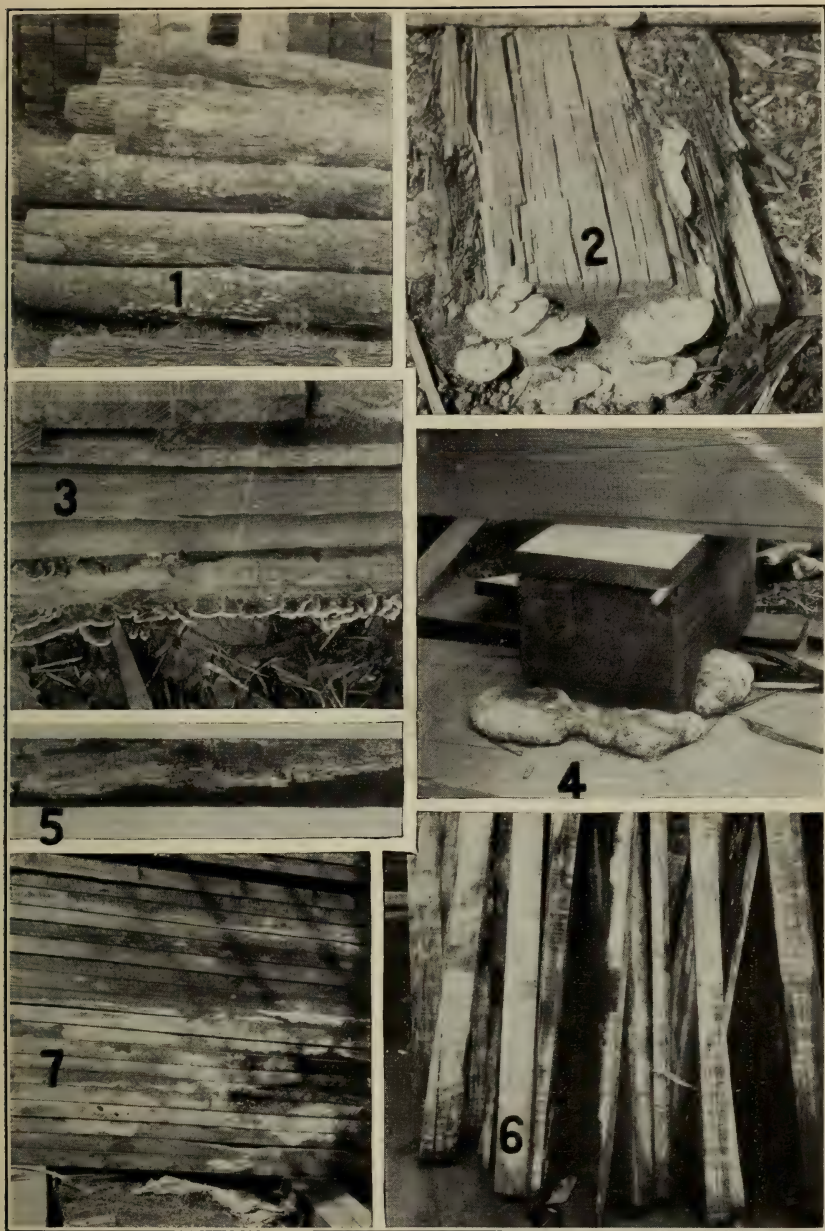


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FIG. 12.—Rotten base of an old hardwood stack upon which sound lumber has been piled. This is a most insanitary practice, as fungous infection will be spread both by the contact of the diseased with the sound lumber and indirectly by the production of fruit bodies and spores, the latter blowing about, reaching sound material, and germinating to produce new infections.

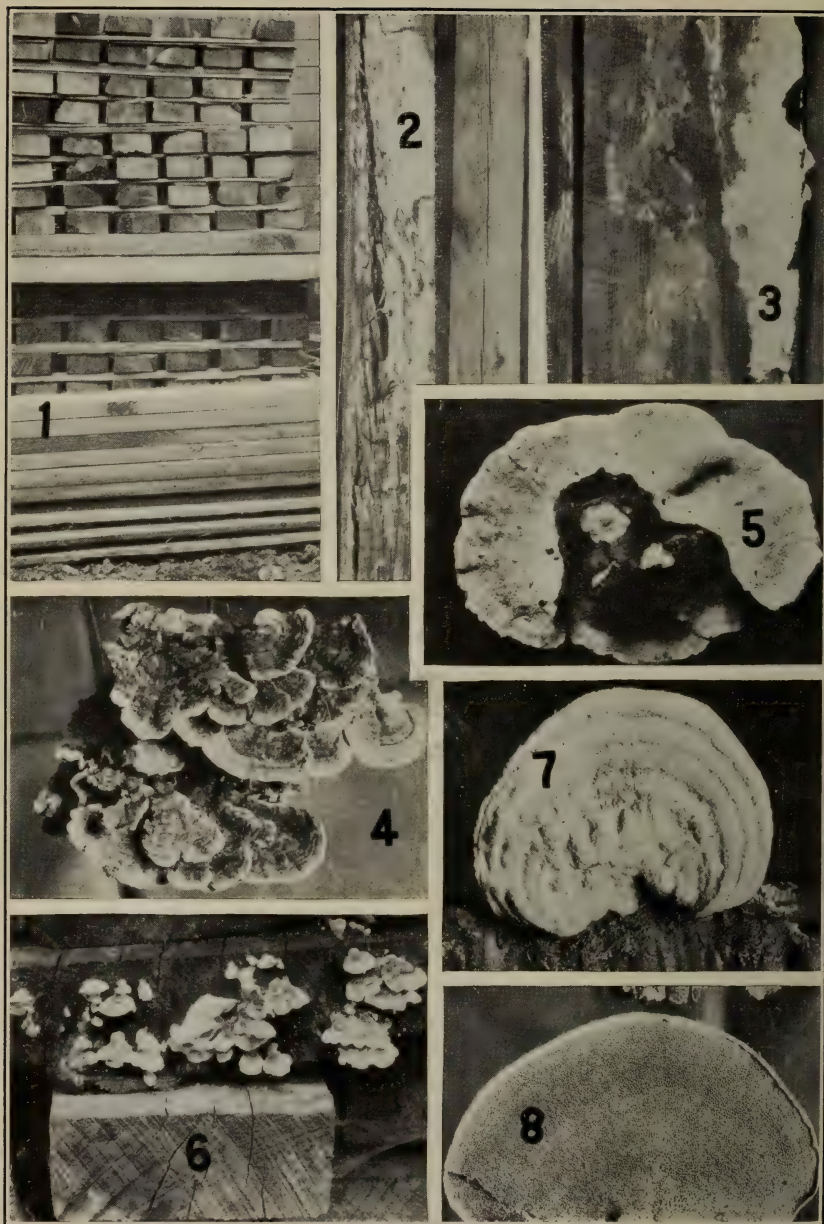
lumber piles either directly by the wind or by convection currents which occur in relatively still air. The proof of this latter form of air currents is often before us in the form of rising mists or fogs.

The first requisite in building foundations is to get them well off the ground, so as to allow ample ventilation beneath, which will dry out the timbers themselves as well as the soil below. A height of at least 24 inches from the top of the skids to the surface of the ground should be adhered to.



LUMBER SANITATION: WOOD-ROTTING FUNGI.—III.

FIG. 1.—A pile of rejected hardwood logs which should have been removed or destroyed and not left to breed fungi (fruit bodies of 6 or 7 different organisms were identified from this pile). FIG. 2.—*Lenzites berkeleyi* fruiting on a hardwood tie. FIG. 3.—Hardwood pile foundations severely infected with *Polystictus versicolor*. FIG. 4.—*Daedalea quercina* fruiting around a foundation block in a Pennsylvania storage yard. FIG. 5.—A badly infected piling stick in use at a Florida mill. FIG. 6.—A group of infected piling sticks at a Tennessee hardwood mill. FIG. 7.—Pile of 3-inch hard pine planks badly infected with *Peniophora gigantea* (a very common condition at Portland, Me.; the fungus is introduced from the South and develops rapidly in close piles).



LUMBER SANITATION: WOOD-ROTTING FUNGI.—IV.

FIG. 1.—Shortleaf pine which has rotted during 10 months' storage in a retail yard at New Orleans. FIG. 2.—A structural pine timber which lay on the ground until severely rotted and was then thrown up into a pile of sound lumber. FIG. 3.—Mycelium of a wood-decaying fungus on the face of pine boards just uncovered in breaking down a pile (at a height of 6 to 8 boards from the bottom, but probably has gone much higher). FIGS. 4 to 6.—*Polystictus versicolor*: 4, Upper surface; 5, lower surface; 6, plant growing on the end of a hardwood board in a lumber pile. FIGS. 7 and 8.—*Polystictus hirsutus*: 7, Upper surface; 8, lower surface.

The use of untreated wood blocking, particularly on low, moist ground, should be discouraged, as such material invariably harbors fungi.

The most desirable practice, and one which would be free from all objections, is the use of concrete or brick piers, preferably the former, and skid timbers treated with some preservative. Such skids, about 24 inches high, treated with creosote, are now in use at the Forest Products Laboratory (fig. 18).

Foundations with concrete piers and untreated skids are at present in use in a number of yards and have given entire satisfaction. At one Mississippi mill (figs. 14 and 19) unfavorable conditions of low ground have been mainly overcome by good drainage, careful attention to the removal of debris, and the use of concrete foundations well off the ground. A description of the foundations and their cost may be of interest.

The foundations were placed and the tramways rebuilt between 1908 and 1910, after a number of years of unsatisfactory experience with wood, at a reported cost of about \$30,000 for a mill having an annual cut around 60,000,000 feet of pine a year. In the two years preceding the placing of the concrete foundations and the rebuilding of the tramways, the annual charge for material and labor in the upkeep of the yard was \$18,000 and \$17,000, respectively. Following the equipment of the yard with concrete foundation piers and concrete footings for the tramway posts, this charge was materially reduced. The present maintenance cost as reported by the company,

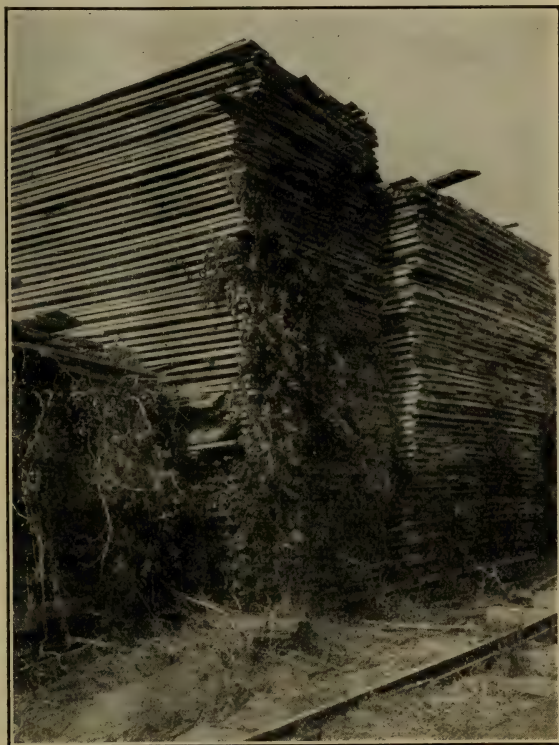


FIG. 13.—Vines growing over lumber piles. From a pathological standpoint this condition should be condemned, because the dense foliage prevents the lumber from rapidly drying out after rains, thus promoting decay.

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FIG. 14.—General view of a mill yard in Mississippi, showing concrete pile foundations and tramway footings. The ditch assists materially in draining the yard. No debris is allowed to accumulate. The stacks are high off the ground and amply ventilated beneath. The tramway and pile foundation timbers would be improved by a preservative treatment with creosote.

mind the advantage gained in preventing deterioration in the stored lumber itself, due to improved sanitation. While this item is very difficult to estimate, the company believes it a very appreciable asset of its storage practice.

The approved type of concrete foundation pier now in use by this company is of the form illustrated in figure 20, consisting of a base block 3 feet square, tapering upward and cast in position. Upon this base block is cast the top block, 2 feet square and also taper-

based on a consumption of 600,000 feet of timber a year at a value of \$12 per 1,000 feet b. m., is \$7,200, or 12 cents per thousand of mill cut. The timber used consists of pine heart seconds having an average life of 5 to 6 years and a maximum life of 8 to 10 years for material not in contact with the ground; pile foundations and tramway footings average 4 to 5 years.

In addition to the direct saving in maintenance charges, we must also keep in



FIG. 15.—A clean, sanitary retail yard, having concrete foundations throughout and creosoted ties in the railroad track.

ing upward, being 1 foot square at the top, which gives a good bearing surface for the horizontal wooden skids or for the vertical posts where it is necessary to elevate the skids to a height consistent with the height of the tramways.

A concrete mixture of 1-2½-5 is used, at a cost for labor and material of \$5 per cubic yard, or an average cost of about \$5 per pier.

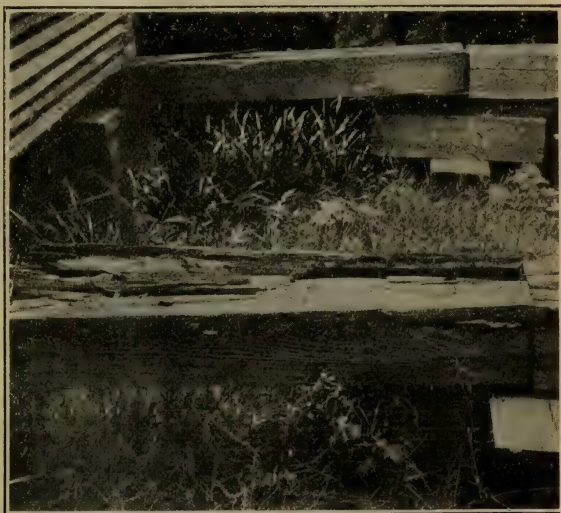
The foundations follow the slightly varying contour of the ground. To compensate for the more marked differences in soil elevation the skid timbers are frequently blocked up to an approximately level condition by the use of short sections of pine posts treated at the ends with a tar or cresote preparation.

There are two advantages in casting the piers in two pieces: (1) The reduction in weight of the individual blocks when it becomes necessary to shift them about the yard, and (2) the greater ease of alignment when erecting the skids.

All the skids are well off the ground at heights never less than 18 to 24 inches and frequently 36 inches and over. The lumber is not piled

directly on the wooden skid timbers, but rests on a 1-inch pine strip, usually about 3 inches wide, to give a smaller bearing surface. This method is not uncommonly employed in various yards. It is of distinct advantage where lumber is piled on infected skids, and if the dry strips are freshly laid for each pile they materially assist in reducing infections in the base of the stack.

In direct contrast to these concrete foundations with ample ventilation beneath, one frequently meets with the type illustrated in figure 21. The one figured is built of 2-inch pecky cypress planks about 14 feet long, resting directly on the ground. The amount of lumber used was computed for one of the squares and totaled approximately 585 feet b. m. While pecky cypress is often used in the South for foundations of this type, in many other cases either non-



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FIG. 16.—Thoroughly rotted pine skids in a mill yard in Texas. Such decayed foundation timbers are very common. Fungous infection can pass directly from these timbers to the lumber piled on them. Creosote would have prevented this condition.

durable hardwoods or the cheaper grades of pine are used. Decay is often serious in such foundations. There is very little chance for ventilation, and this often leads to storage rots in the base of the piles.

The open type of foundation is always much the better from a pathological standpoint. In certain of the Gulf cities, where municipalities in cooperation with the United States Public Health Service are making strong efforts to get rid of rats to safeguard against the bubonic plague, certain ordinances have been passed requiring structures to be raised at least 12 inches from the ground and left open beneath. This requirement will react very favorably upon

lumber storage; for the first necessity is to get the timber off the ground, with ample ventilation beneath. Figure 22 illustrates the method of elevating the skids employed in a retail lumberyard at Mobile, Ala., which has only recently occupied the premises.

Timber foundations are frequently the cause of considerable trouble on account of decay failure under heavy loads, thus allowing the piles to topple over or to crush to the ground, where they have every opportunity to rot. Figure 23 shows two such piles at a South Carolina mill. Rot in foundation timbers is extremely

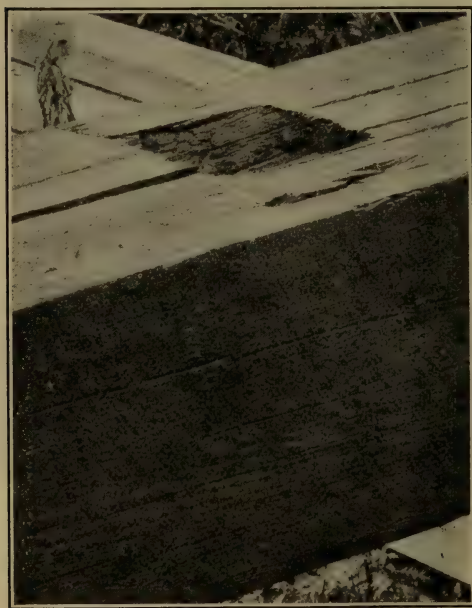


FIG. 17.—A 12 by 12 inch hard-pine timber, showing a rotten hole in the face which lay in contact with infected skids.

common and, in fact, has been encountered in practically every yard examined where timbers are employed for this purpose.

PILING STICKS.

Practically all yards in which the lumber is "stuck" fail to appreciate the necessity of keeping the sticks free from infection. The strong tendency is to scatter them about on the ground wherever they happened to fall when the previous piles were taken down (fig. 24). In a very few yards attempts are made to improve the appearance of the premises by gathering the sticks endwise into conical piles or by stacking them carefully on the ground beneath the skids (fig. 25).

This question of the sanitary handling of the piling sticks is of very great significance, particularly in regions of high humidity, where every precaution must be taken to safeguard stored lumber. Plate III, figures 5 and 6, shows such infected sticks found in Florida and Tennessee lumberyards, where several species of wood-destroying fungi were frequently noted in the piles.

When one keeps in mind the fact that the soil in and about lumberyards often becomes, in the course of time, thoroughly intermixed with sawdust and

partially decomposed woody matter which offers a fertile field for the development of wood-destroying fungi, the necessity of keeping all

sound material out of contact with it becomes very evident. In cases where sawdust and bark or wood débris are used to produce artificial fills the danger is further increased. Such filling materials are not infrequently used.

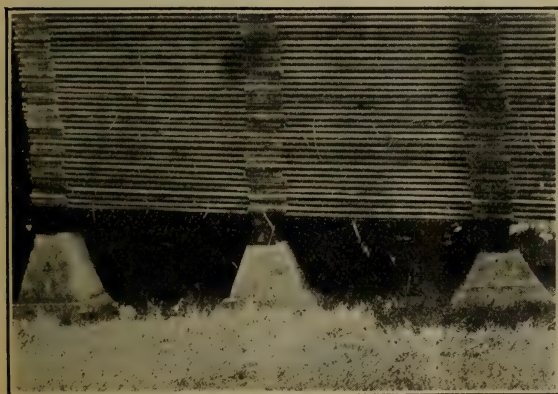
Such situations introduce the further question as to what material should be used for filling in

low portions of the yards. While the material used will necessarily be governed largely by local conditions, it is the opinion of the writer



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FIG. 18.—Pile foundations consisting of creosoted timbers resting on concrete piers in use at the Forest Products Laboratory, Madison, Wis. This is a very satisfactory type of foundation.



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FIG. 19.—Concrete foundations with untreated skid timbers in general use in a mill yard at Laurel, Miss. Only two rows of piers are used for stock 14 feet or less in length.

that clean clay or sandy soil will serve the purpose admirably. While sandy soil allows fungi to spread within it more rapidly than clay, it offers the advantage of rapid seepage, and where the surface is

amply ventilated no difficulty should be experienced. (Pl. X, figs 1 and 3.)

The principal need is to have the yards so laid out that surface water will not accumulate. Ordinary ashes are not considered a good filling or surfacing material, since they absorb moisture readily and hold it tenaciously, particularly when

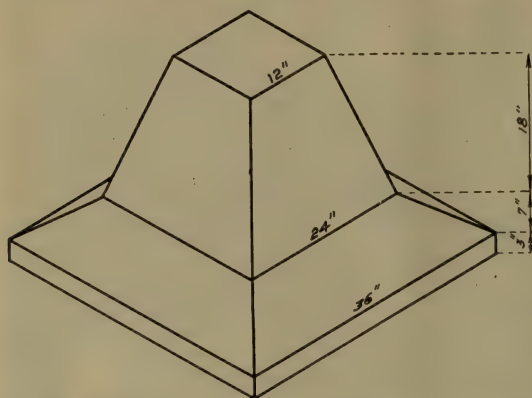


FIG. 20.—Sketch of a concrete foundation pier in use in a mill yard in Mississippi. It is cast in two sections, for convenience in aligning and moving about the yard.

they are in a finely pulverized condition. Less finely divided material, such as coarse cinders, gravel, or slag, is better adapted on account of the rapid seepage. Moreover, wood-destroying fungi appear to grow through ashes quite readily when they are in a moist condition. In fact, the writer has a record of one case where fungi developed luxuriantly in a pile of ashes in the open when exposed to prolonged rainy weather. (Pl. IX, fig. 3.)

METHODS OF STACKING LUMBER.

Lumber piled in the open must be allowed ventilation around the individual pieces, and this is usually arranged for in storage practice.

In some instances, however, this necessity is ignored in certain



FIG. 21.—Pecky cypress foundations in use at a mill in South Carolina. Each large square contains from 500 to 600 board feet. This type of construction does not allow sufficient ventilation beneath the piles.

retail yards where it is the custom to dispose of the stock within very short periods, say, two or three months. In some of the northern retail yards along the Atlantic coast, where southern pine comes in by boat in a comparatively green condition, this practice often leads to severe fungus infections throughout entire piles. This infection undoubtedly gets a good start in the hold of the vessel during transit and propagates further when close piled in congested lumberyards. Such a pile of diseased pine is



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FIG. 22.—Foundations at Mobile, Ala., built to conform to an ordinance requiring all structures to be raised at least 12 inches off the ground and left open underneath.

shown in Plate III, figure 7, where the infection extends up high into the stack.

It is not the intention in the present bulletin to enter into a discussion of detailed methods of stacking lumber. The primary concern, from the standpoint of sanitation, is to dry the lumber as rapidly as possible and maintain it in this condition. However, other considerations, such as checking and warping, must be taken into account in many instances. The humidity or dryness of the climate will be of great weight in determining the proper amount of ventilation to give the best results from all standpoints.

Certain general considerations, however, apply to practically all cases. The method of using special narrow cross sticks is probably



FIG. 23.—Foundations which have failed through decay, permitting the piles to topple over. This would have been prevented by the use of a good preservative.

would also accrue with the use of sticks cut from highly durable material; for instance, resinous heart pine or resistant hardwoods, such as white oak and heart red gum.

The second general method of piling lumber consists in using the narrower widths of the lumber itself for crossing strips (fig. 26). The wider boards ordinarily offer too much of a bearing surface for good air circulation. At one of the Arkansas mills visited it was customary in the earlier days to use the regular run of lumber up to 12

inches wide as crossers, but this practice was discontinued on account of the serious loss from decay. The manager of the mill informed the writer that considerable rot would occur in 8 to 12 inch stock

in greatest use, and this offers certain advantages when the sticks are handled in a sanitary manner. In the first place, the strips are kept in an air-dry condition, which offers considerable advantage over green material; in the second place, the strips, being narrow, do not offer a bearing surface more than 1 to 4 inches wide. A distinct advantage

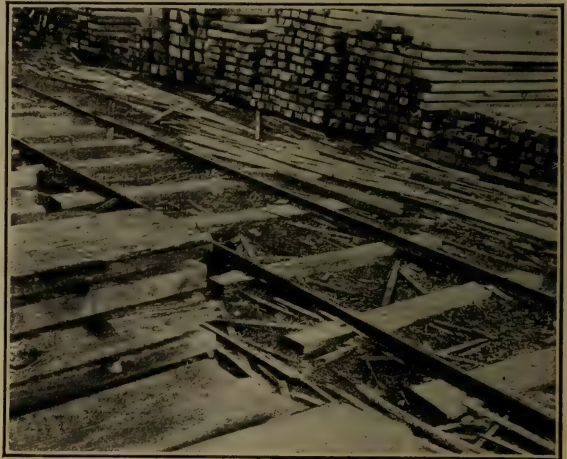


FIG. 24.—Piling sticks lying on the ground at a mill in South Carolina, showing the insanitary method of handling them. Such sticks lying for only a week or two in contact with fungus-infected ground may themselves become seriously infected, and decay may in turn pass on to the lumber stacks.

within a year under such conditions. The present practice is to use strips 4 inches wide and 1 inch thick of air-dry No. 2 pine. This method has proved entirely satisfactory.

In laying sticks careful attention should be paid to placing the successive strips vertically one above the other. If they are placed hit or miss, certain ones may fall in the span of the next tier below, thus producing much unnecessary warping of the lumber, due to the pressure of the overlying layers.

In all cases of flat piling of green lumber care should be taken to leave a space of at least half an inch between the edges of the stock. This gives a vertical air circulation, which is particularly effective.



FIG. 25.—Piling sticks placed on wet ground beneath the skids. In order to keep them free from infection, such sticks should never be placed in contact with the soil.

Two other methods of piling 2 to 3 inch stock are used to some extent with good results. The edge piling of 2 by 4's (fig. 27), sticking the pieces in the usual way, has given good results at several mills where flat piling produced an appreciable amount of deterioration. The method of flat piling without the use of sticks, occasionally employed with 2 by 6's, in which horizontal circulation is provided for by leaving wide spaces between the edges of the stock (fig. 28), would not appear to offer as good opportunities for drying lumber in a moist climate as the more usual method which makes use of sticks.

Besides the proper sticking and lateral spacing of lumber, a central flue one board wide running vertically through the middle of the pile is often of decided advantage. Many millmen recognize this as good practice, but few of them consider they have sufficient yard space to carry out the method consistently.

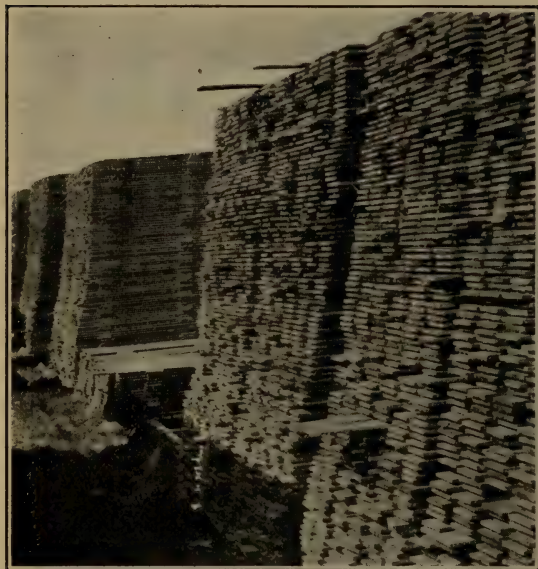


FIG. 26.—Lumber piled in even lengths in a southern mill yard. The crossing strips consist of the narrower widths of lumber.

Another factor which enters into the storage of lumber is the piling of stock in even or approximately uniform lengths (see fig. 26). A few mills consider that such preliminary sorting is feasible from an economic standpoint, on account of the greater facility with which such stock can be billed out. From a pathological standpoint the practice is highly commendable.

Uneven lengths allow rains to beat in, and also offer convenient and favorable lodging places for fungous spores. Likewise, marked disparities in length permit considerable warping of the ends, which often project out several feet from the main body of the pile. Figure 29 shows this condition in an exaggerated form. To protect the ends of the lumber from beating rains as far as possible, the cross strips should be placed at least flush with the ends, both in front and behind.

There still remains the question of roof-



FIG. 27.—Edge-piled 2 by 4 pine at an Arkansas mill. This method of piling permits better vertical air circulation and consequently more rapid drying and less danger from decay during storage.

ing the piles. The commonly accepted pitch for lumber piles is 1 inch to the foot, and with a loose roof of lapped boards the greater part of the rainfall will drain away. The roofs must necessarily extend somewhat beyond the piles, in order to carry the drip clear of

the stack at the rear. Roofing the piles should never be omitted, as the protection afforded against rain is of undoubted value and the operation itself adds very little to the cost of piling.

HANDLING TIMBER AT RETAIL YARDS.

The storage problems involved at retail yards are somewhat different from those at mills, although they may be discussed under exactly similar heads.

LOCATION OF YARDS WITH REFERENCE TO DECAY.

As a first observation, we may say in general that retail or wholesale yards, as opposed to yards in connection with a sawmill, have the advantage of a higher and drier location, which, in turn, should make sanitation measures easier to practice. The necessity of locating on streams or bodies of water is not ordinarily a prime consideration, but rather the location on or near a railway line and as convenient as possible to the actual consumer. Naturally, in the seaport towns, where much of the lumber comes in by boat, the most favorable location from the standpoint of transportation is along the water front, but in inland towns, where the shipment of lumber is by rail, the other factors of accessibility to the local market and the price of land play the important part.

This general advantage of location, however, is often considerably offset by the necessity for close piling, without adequate ventilation either between the piles or through them, due to the higher cost of land. When this is coupled with the fact that much of the product has been in storage elsewhere for varying periods, sometimes a year or more, it can readily be seen why decay is rather frequently encountered in the retail yard.

The salvation of the retail dealers usually lies in disposing of their stock rapidly. Most of them aim to turn it at least three or four times a year, for they recognize that long storage will prove disastrous. Timber showing deterioration through decay is not difficult to find in most retail yards. However, this is very often only in the

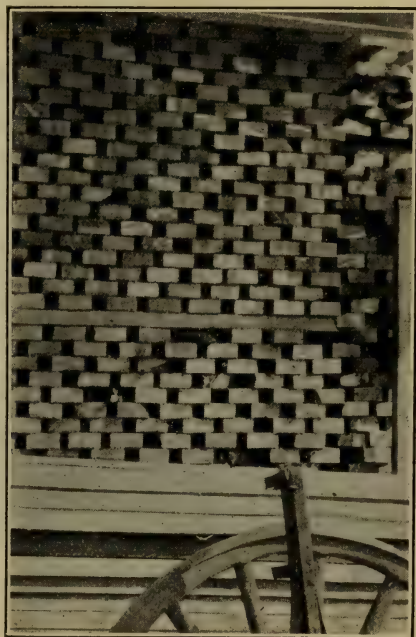


FIG. 28. — Two-inch stock piled without sticks, a method rarely used in the yards visited. Not used, as far as observed, with stock less than 6 inches wide.

incipient stage and is not readily noticed by the casual observer. Yards which dress the lumber just before filling orders can in this way supply to the trade clean-looking lumber, but this does not always imply freedom from fungous infection. The opinion seems to be prevalent among many lumber dealers that the mere brightening of the lumber by running through the planer serves to remove all objection to infected stock. This is far from the fact, however. It merely gives it a better sale appearance, and the danger to the ultimate user still remains. The adage that "beauty is only skin deep" applies to such infected stock with particular force.

While perhaps the majority of lumber dealers have merely overlooked the full significance to the building trades of the dangers which lurk in diseased stock and are trying in every way to satisfy their trade and meet competition, there still remain a considerable number who do not look into the future but are content to get the stock off their own hands without any care as to the service which it will give the consumer. This is a thoroughly mistaken policy, for

the lumberman should in every way strive to increase the value of his product. In the first place, it is good business policy, and, second, there remains the question of moral and legal responsibility.

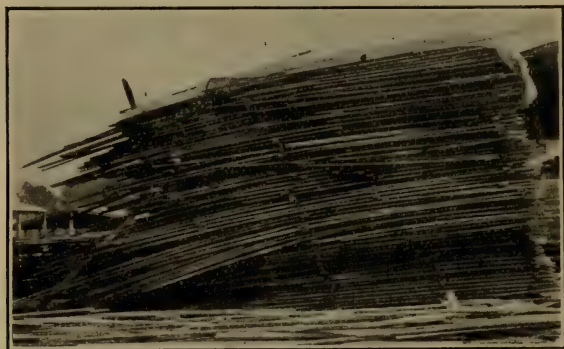


FIG. 29.—A stack of pine lumber of uneven lengths. Note the irregular distribution of the piling sticks and the consequent warping and twisting of the boards.

STORAGE SHEDS.

In many retail yards shed conditions are very poor. The closed type of shed is in the minority. Since lumber under cover is as a rule piled closely in bins, the need for ample ventilation beneath and a tight roof above is imperative. All the decay observed in lumber sheds is directly traceable to one or the other of these factors; mainly, however, that of improper ventilation. It has frequently been the custom merely to lay a narrow timber sill directly on the ground, or at best within a very few inches of it, to serve for the foundation (fig. 30). The best practice, however, has been to place the sills on brick or concrete piers not less than 18 to 24 inches high, running the siding of the shed only to the bottom of the sills, so as to allow a free circulation of air regardless of the direction of the wind. Such a construction is represented in figure 31.

Another defect of the open shed which has been frequently noted is the strong tendency to allow the ends of the longer stock to project

beyond the eaves (fig. 32). Very few sheds are equipped with gutters (fig. 31), and the drip during rains may run back along the projecting pieces well into the center of the piles. When once wetted the close piles will retain this moisture for long periods, during which a serious outbreak of decay may be initiated.

A few cases of severe outbreaks in retail lumber sheds will be described and illustrated later.

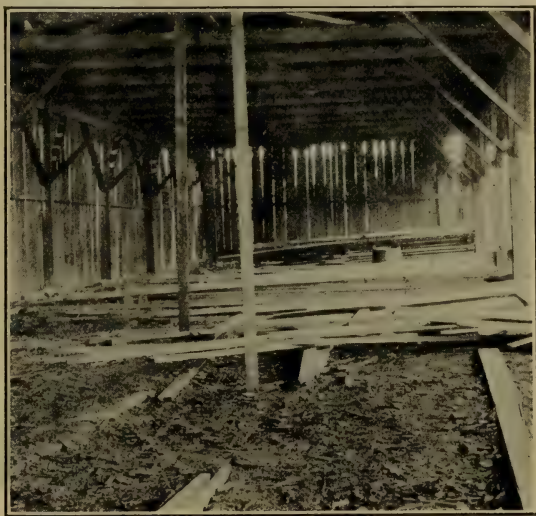
YARDS.

On account of very limited storage space, nearly all retail yards fail to observe the proper spacing of lumber to insure ample ventilation. The general tendency is to pile altogether too close to the ground for safety, and in many instances the lumber is not spaced as well in the piles as it should be (fig. 33).

The principal danger lies in the foundations, which are very often seriously infected with rot (fig. 34) or are not adequately constructed to insure proper ventilation. The danger in allowing lumber to come in contact with the soil is evident in figure 35. As the question of foundations in mill yards was discussed in considerable detail earlier in this publication and since the fundamental considerations apply with

equal force to retail yards, only certain features which serve to connect these fundamentals with the direct problems of the retail yard will be added here.

Many retail lumber yards use solid or latticed foundations of built-up plank running parallel to the alleys (figs. 36 and 37); others resort to wood blocking for the support of the skids. The use of concrete is very limited, but has given complete satisfaction wherever introduced. It is usually laid down as solid foundations parallel to the alleys. In one yard at Birmingham, Ala., the foundations were 8 to 10 inches high, 6 inches thick at the top, and placed in triple parallel rows spaced 7 feet apart (fig. 38). The advantage of reinforcing the concrete is well shown in figure 39.



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FIG. 30.—An old, dilapidated shed on the Mobile River in which the lumber is too close to the ground. Many severe cases of rot have developed under just such conditions.

Somewhat higher foundations than these are to be preferred in many situations, but in this yard, where every precaution was taken to keep the ground free from all infected débris, and where the drainage was excellent, this height has proved satisfactory.

Piers have the advantage over a solid wall in permitting better ventilation, but piers also involve the use of wooden skids, which if not treated with a good preservative may more than offset the advantage gained in better ventilation.

The careless handling of crossing sticks and lumber in retail yards



FIG. 31.—A retail shed in Tennessee, well roofed, provided with gutters, and set on brick piers with ample ventilation beneath from all sides.

is just as evident as in mill yards. The general practice in many of the yards visited is to throw sticks about on the ground when the stacks are torn down, and there they often remain until they are needed again. This insanitary practice needs no further comment. A comparison of the yard shown in figure 40, where the lumber is scattered about promiscuously on the ground, with the yard shown in figure 15, where concrete foundations and treated ties are in use and all débris is carefully

collected into a wagon (fig. 41) and hauled away, may be of interest in this connection.

FUNGI WHICH ROT STORED LUMBER.

A considerable number of different species of wood-destroying fungi have been encountered in lumberyards. These, of course, are more frequently found fruiting on the foundations, tramway timbers, and ties than on the stored lumber, but this is only a question of the time which the timbers have been in the yard. The fact that elevated tramway posts and girders will rot in the South in a few years is proof conclusive that lumber stored in the open will also rot if it becomes necessary to hold it in storage too long. In the Gulf States low-grade lumber stored in the ordinary manner will show consider-

able deterioration within a year. Plate IV, figure 1, shows a small pile of shortleaf pine seriously rotted after a period of only 10 months in a retail yard at New Orleans; in fact, the owner of this yard suffered so much loss from decay in the less durable grades of pine that he has discontinued handling them.

Fungi are in evidence in lumberyards in the vegetative stage (moldlike growths; Pl. II, fig. 1, and Pl. IV, figs. 2 and 3) and in the fruiting stage. Almost any species occurring in a given region may occasionally be introduced into storage yards, but the great majority of the specimens found fruiting fall within a comparatively few species.

One of the common forms, *Polystictus versicolor* (L.) Fr., is shown in Plate IV, figures 4, 5, and 6, growing both from the ends of stored hardwood lumber and from built-up plank foundations (Pl. III, fig. 3). This organism is profusely distributed throughout the entire United States and is more destructive to hardwood timber than any other fungus.

Other members of this genus, such as *Polystictus hirsutus* (Schräd.) Fr. (Pl. IV, figs. 7 and 8), *P. pargamensis* Fr. (Pl. V, figs. 1 and 2), and *P. abietinus* Fr. (Pl. V, figs. 3 and 4) are likely to be found in most lumberyards throughout the United States, occasionally fruiting on stored lumber, but more often causing sap rots of tramway timbers, foundations, and ties. The last species grows on coniferous timber almost exclusively; the other two on hardwood timber.

Among other members of the true pore fungi may be mentioned *Polyporus adustus* (Willd.) Fr. (Pl. V, figs. 5 and 6), which is usually thin, tough, and leathery, creamy above and smoky below; *P. sanguineus* (L.) Fr. (Pl. VI, fig. 4), of a bright red through-



FIG. 32.—A retail shed in Alabama in which the lumber projects beyond the eaves, thus catching the drip from rains. This condition favors decay when the water runs back along the boards into the piles.

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out, shiny above, rather thin and shelflike, which is found abundantly throughout the South on hardwood timbers; and *P. gilvus* Schw. (Pl. VI, figs. 2 and 3), a firm, comparatively thin, rather rigid species, yellowish within and reddish brown without as it ages.

In the northeastern United States one occasionally finds on oak or chestnut timbers the heavy, tough, corky fruit bodies of *Daedalea quercina* (L.) Pers. (Pl. VI, fig. 1). When the plant develops normally it forms large and sinuous pores, but in lumberyards it more often appears as abortive clay-colored cushions (Pl. III, fig. 4). It is one of the few fungi which attack white oak and chestnut.

Another destructive group of fungi is represented by the genus *Lenzites*. Among the brown species there are three principal ones to

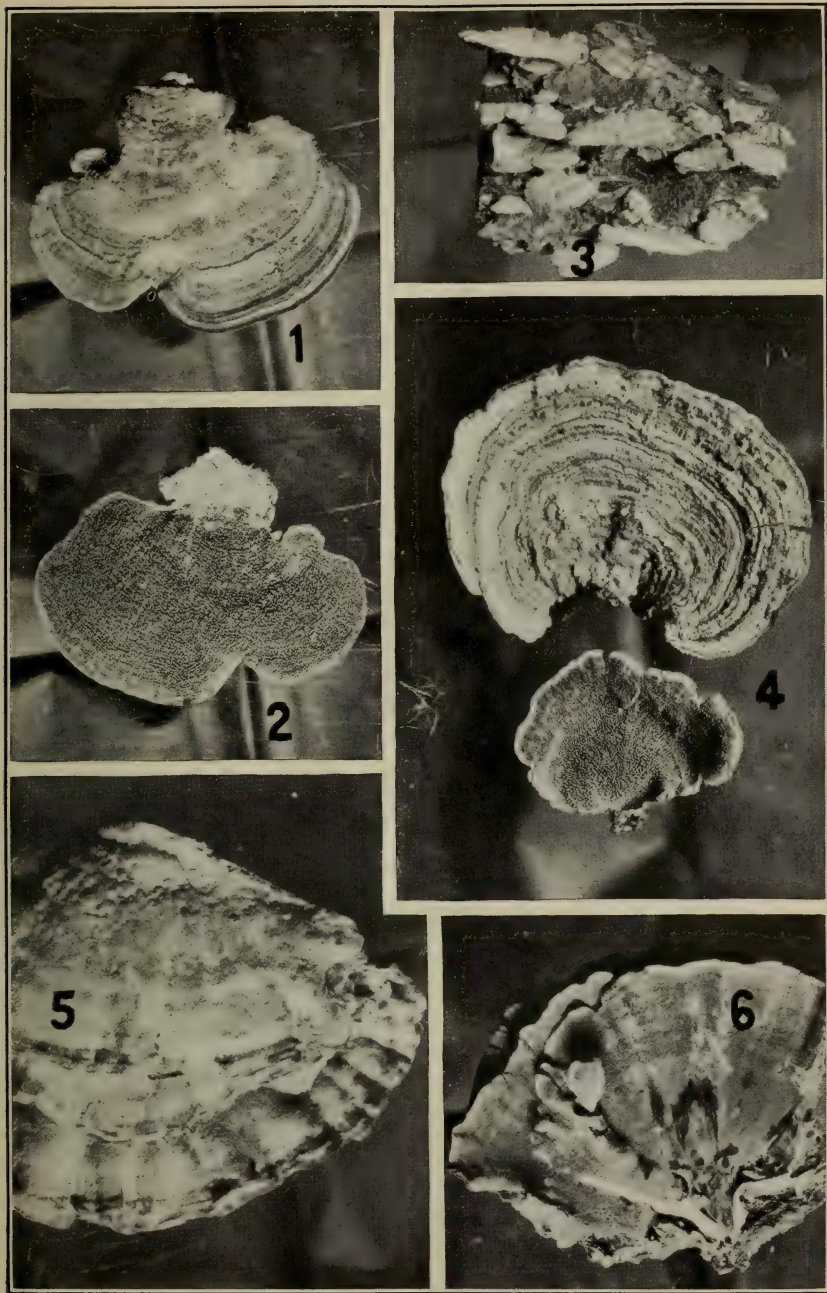


FIG. 33.—A very congested retail yard at New Orleans, La., showing lumber temporarily placed on the ground in solid piles. This is a bad practice, because under such conditions decay may start in a very short time.

be feared: *Lenzites sepiaria* (Wulf.) Fr. (Pl. VI, figs. 5 and 6), *L. berkeleyi* Sacc. (Pl. VI, fig. 7), and *L. trabea* (Pers.) Fr. (Pl. VII, fig. 1). The first two constitute the most serious enemies of coniferous structural timber in the United States. The last species rots both the heartwood and sapwood of many different kinds of hardwoods. All three are brown throughout and leathery to corky in texture. In some fruit bodies the

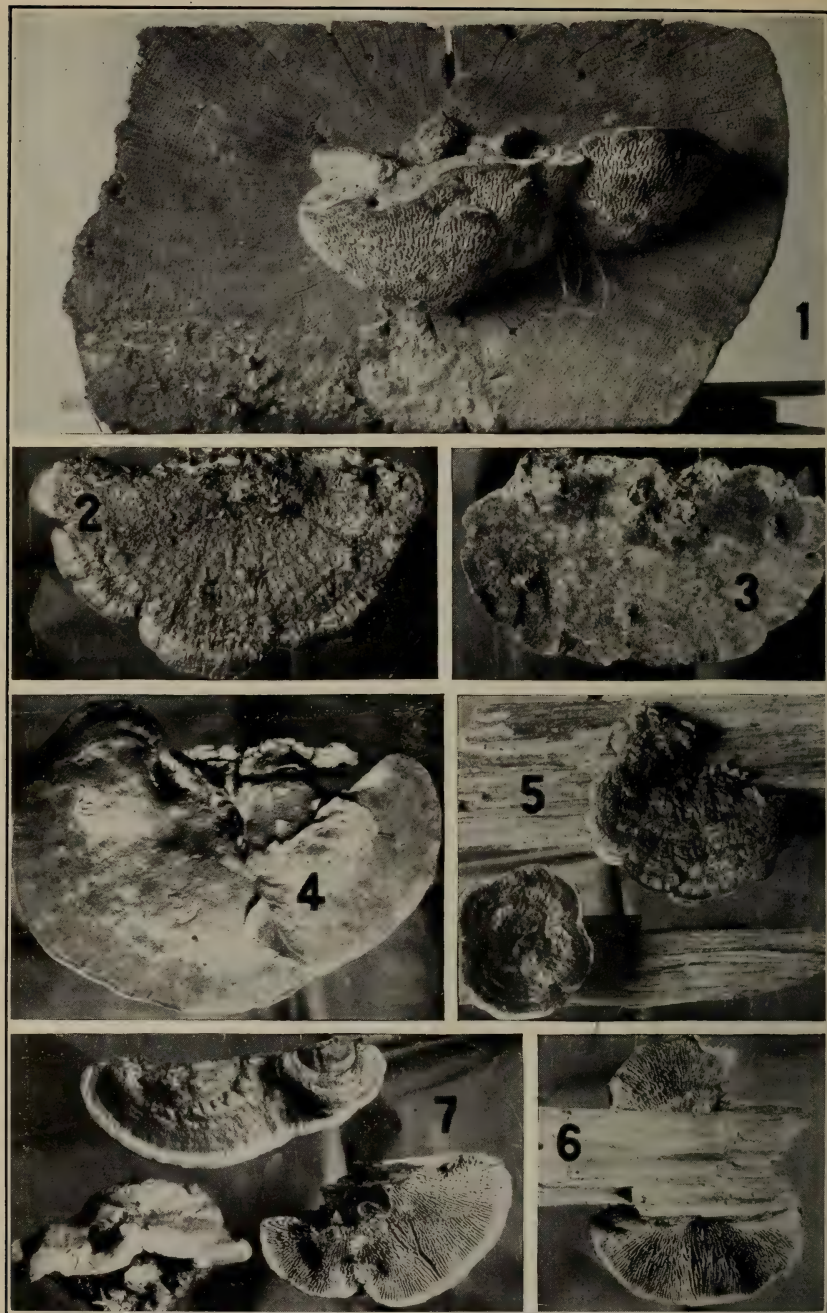
under surface may consist of distinct gills; in others, the gills may more or less run together to form sinuous to subcircular pores, easily visible to the naked eye.

Another species, *Lenzites betulina* (L.) Fr. (Pl. VII, figs. 2 and 3), of a general creamy color, with an upper surface frequently banded with shades of yellow, orange, and brown, occurs on hardwood timber throughout the United States. It has commonly been noted in lumberyards on timbers used in various structures. In one large mill yard where oak was largely used for planking the elevated tramways, this species, in conjunction with *Polystictus versicolor*, suc-



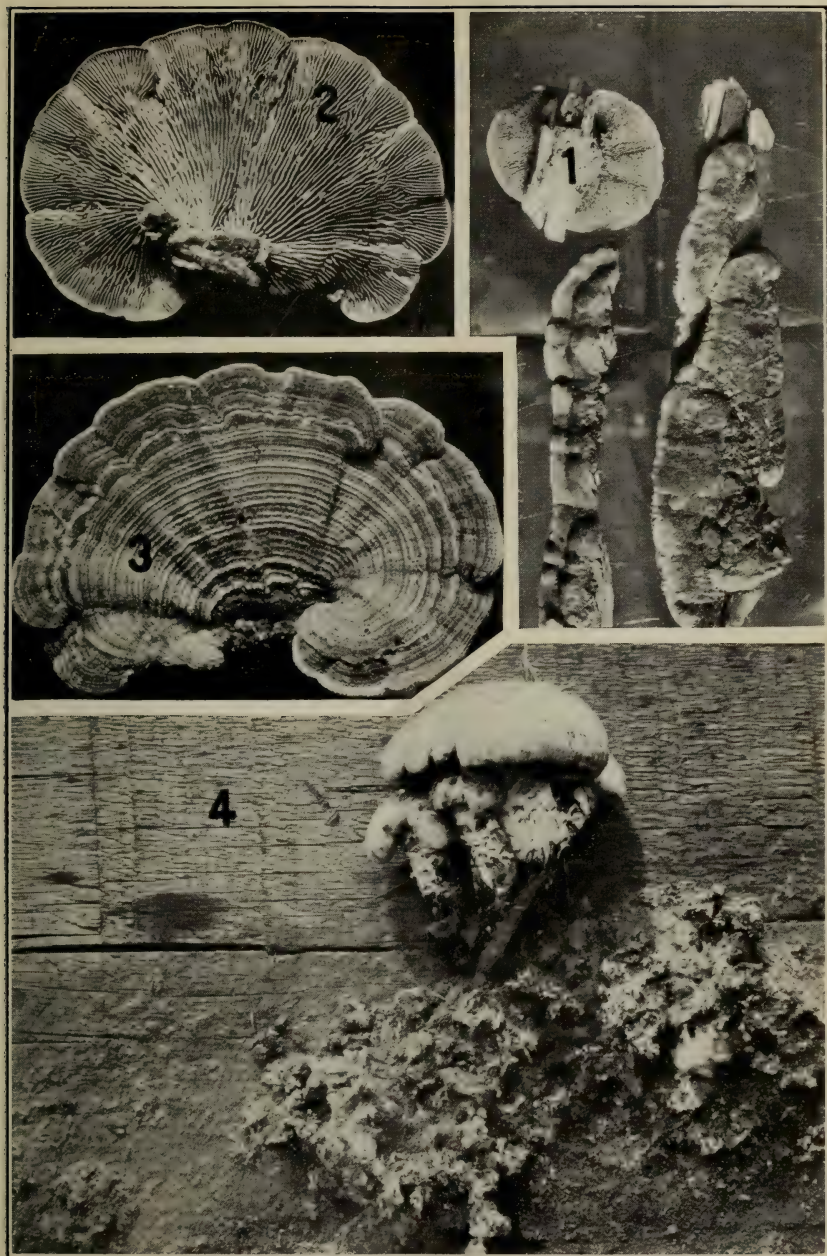
LUMBER SANITATION: WOOD-ROTTING FUNGI.—V.

FIGS. 1 and 2.—*Polystictus pargamensis*: 1, Upper surface; 2, lower surface. FIGS. 3 and 4.—*Polystictus abietinus*: 3, Typical form from a pine log; 4, plants showing upper and lower surfaces. FIGS. 5 and 6.—*Polyporus adustus*: 5, Upper surface; 6, lower surface.



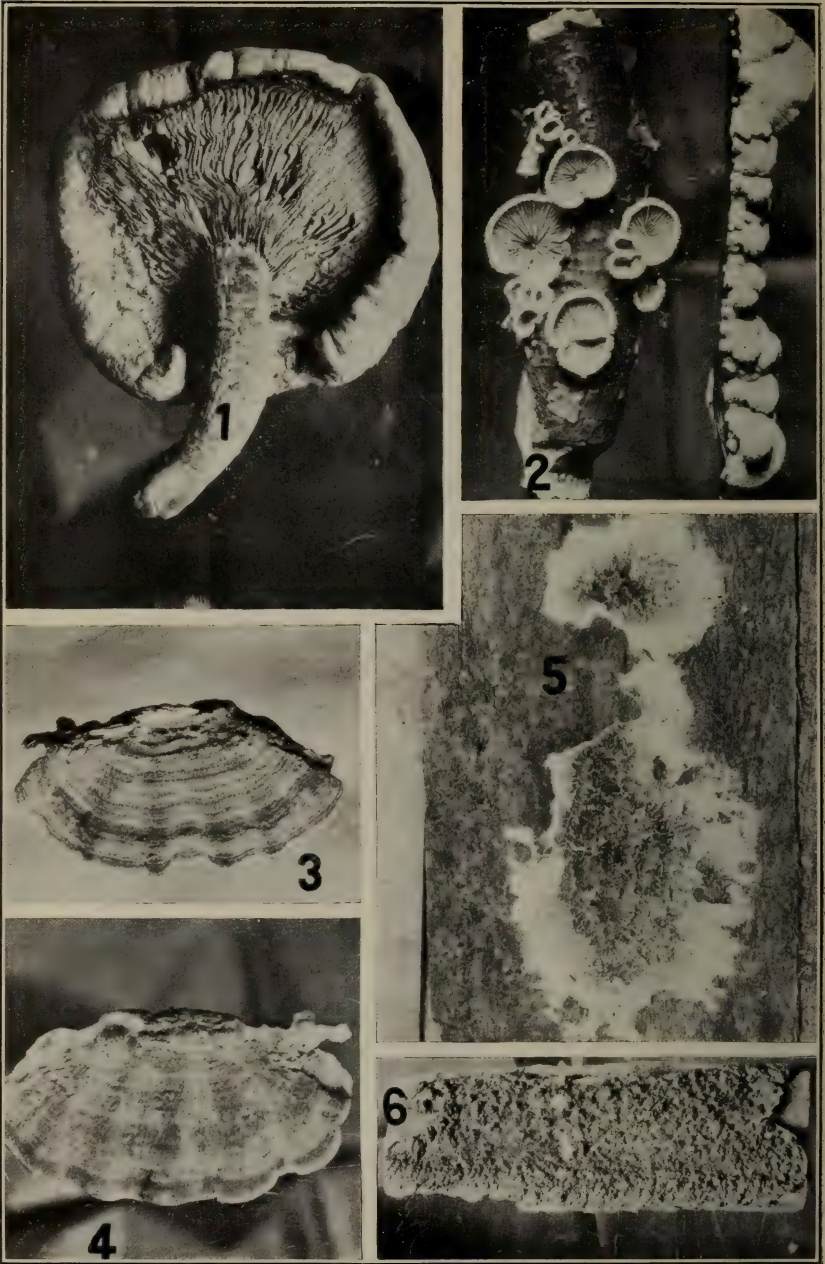
LUMBER SANITATION: WOOD-ROTTING FUNGI.—VI.

FIG. 1.—*Daedalea quercina* growing on an oak tie. FIGS. 2 and 3.—*Polyporus gilvus*: 2, Upper surface; 3, lower surface. FIG. 4.—*Polyporus sanguineus*, upper surface. FIGS. 5 and 6.—*Lenzites sepiaria*: 5, Upper surface; 6, lower surface. FIG. 7.—*Lenzites berkeleyi*, upper and lower surfaces.



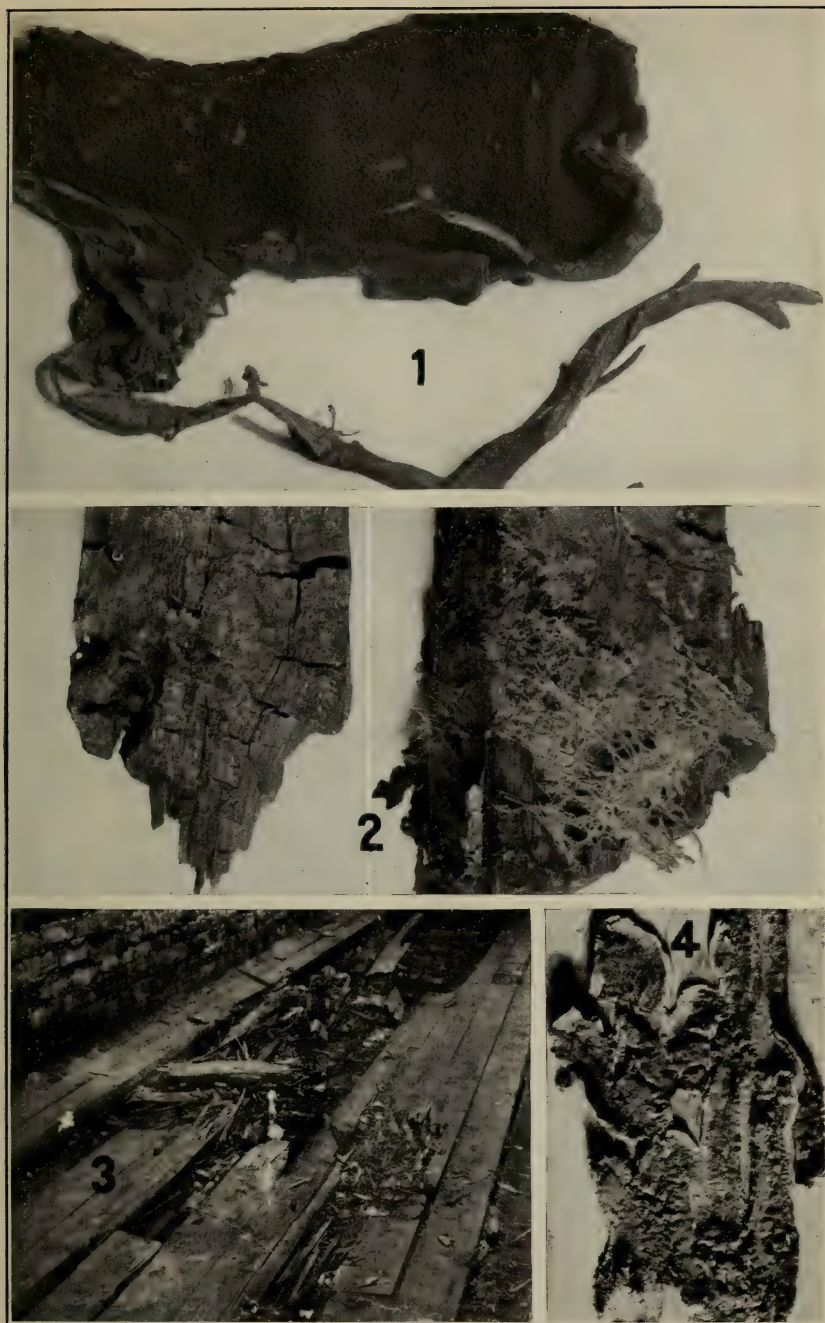
LUMBER SANITATION: WOOD-ROTTING FUNGI.—VII.

FIG. 1.—*Lenzites trabea*, upper and lower surfaces. FIGS. 2 and 3.—*Lenzites betulina*; 2, Lower surface; 3, upper surface. FIG. 4.—*Lentinus lepideus*, typical form on railway ties.



LUMBER SANITATION: WOOD-ROTTING FUNGI.—VIII.

FIG. 1.—*Lentinus lepideus*, under surface. FIG. 2.—*Schizophyllum commune*, upper and lower surfaces. FIGS. 3 and 4.—*Stereum fasciatum*: 3, Upper surface; 4, lower surface. FIGS. 5 and 6.—*Coniophora puteana*: 5, Smooth form growing on spruce sheeting in a mine; 6, warted form from a mine.



LUMBER SANITATION: WOOD-ROTTING FUNGI.—IX.

FIGS. 1 and 2.—*Merulius tachrymans*: 1, A well-developed fruit body with porous moisture-conducting strand (from a residence in Pennsylvania); 2, mycelium growing over the surface of the rotten wood. FIGS. 3 and 4.—An unidentified fungus in a Mississippi cotton warehouse; 3, flooring rotted by the organism; 4, fruit bodies developing on other parts of the floor. (This is the same species illustrated in Plate X, figures 1 and 2.)



LUMBER SANITATION: WOOD-ROTTING FUNGI.—X.

FIGS. 1 to 4.—A severe infection of an unidentified fungus in an Alabama lumber yard: 1, Open shed where the fungus has progressed upward to the second bin, 5 feet from the ground; 2, corner of closed shed on the same premises where rolls of tarred roofing paper resting on the floor (not shown in the picture) were severely rotted at the ends; 3, the shed shown in figure 1, showing how the infection started by piling too close to the ground over a cinder fill; 4, the same shed after the lower bins had been raised in an effort to control the spread of the rot. FIGS. 5 and 6.—*Peniophora gigantea*: 5, Intermixed with molds and developing on moist pine shingles in a close pile in a Tennessee retail yard (growth, which an antiseptic dip at the mill would have prevented, had started during transit); 6, the mature stage growing on a pine log.

ceeded in rotting the planks at practically the same rate at which they wore down mechanically.

Of the true gill fungi may be mentioned two species—*Schizophyllum commune* Fr. (Pl. VIII, fig. 2) and *Lentinus lepideus* Fr. (Pl. VII, fig. 4, and Pl. VIII, fig. 1). The former occurs everywhere in the United States on both coniferous and hardwood timber. It is white to grayish, very thin and flexible, woolly above, and has very distinct gills below, which are split longitudinally at the edge and each half curled over, much as a dandelion stem curls when split. It is a comparatively small fungus, usually not projecting out more than 1 or 1½ inches. At times it is attached at the center of the back and then presents a circular outline with the gills radiating from a common center. When dry it is much curled and in-rolled, but during rainy weather it readily revives and appears fresh and expanded again. Fortunately, it deteriorates wood but slightly and need occasion no fear among lumber users.

Lentinus lepideus Fr. is a fungus of the "toadstool" type, with a circular, broadly convex, scaly cap, and a stout, fibrous, central or eccentric stem. It is white throughout, except for the brownish scales on the upper side of the caps and on the stem. The under side is provided with coarse gills, which become considerably toothed and split as the plant ages.

This fungus is a very rapid grower and primarily attacks timber in contact with the soil. It rots pine railway ties very rapidly, growing through sandy soil from one stick to another. Serious outbreaks of the fungus in pine warehouse floors have been reported several times, and it should be carefully guarded against in lumber storage yards.

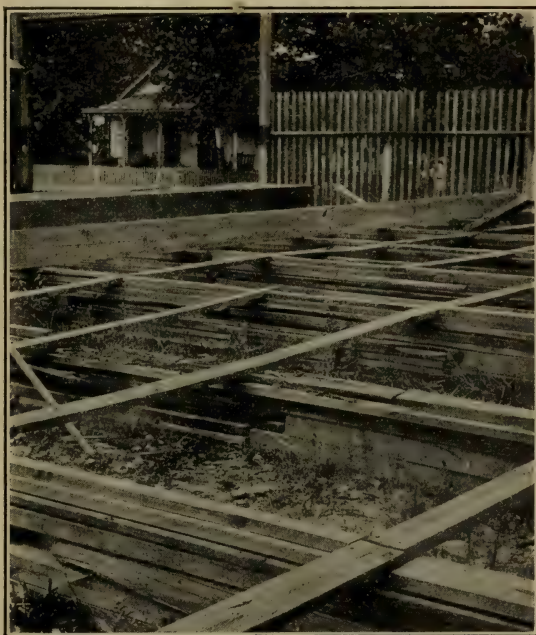


FIG. 34.—Built-up pine foundations in a retail yard in Tennessee. Many of the foundation timbers are seriously decayed and infection may pass to timbers piled in contact with them. Figure 17 shows what happened to a structural timber placed on a foundation in this yard similar to these.

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Of the fungi having a smooth under surface, two species are common enemies of structural timber—*Stereum fasciatum* Schw. (Pl. VIII, figs. 3 and 4) and *S. lobatum* Knze. These fungi are too much alike for the layman to attempt to distinguish between them. They are very thin and flexible, the individual shelves often growing one above the other. The general color is grayish to creamy.

Among the incrusting forms three deserve particular attention, viz, *Merulius lachrymans* (Wulf.) Fr., *Coniophora puteana* (Schum.) Fr. (= *C. cerebella* (Pers.) Schröt.), and *Peniophora gigantea* (Fr.) Mass. The first two species are notoriously dangerous and have been found in a number of lumberyards extending from Massachusetts to the Gulf of Mexico. They are also the most frequently reported of all fungi occurring in buildings, and also the most destructive.



FIG. 35.—Projecting ends of lumber which have decayed by coming in contact with the ground.

Merulius lachrymans (Pl. II, figs. 1, 2, and 6, and Pl. IX, figs. 1 and 2) is a soft, subgelatinous fungus, forming a brown, crumpled growth with a white, fluffy margin over the surface of timber. As it develops it produces dirty gray to brownish minutely porous strands, which serve for the conduction of water, thus enabling the fungus to spread rapidly over comparatively dry substrata.

For this reason it has been frequently termed the "dry-rot fungus." On account of its destructiveness to buildings in Europe it also goes under the German name "Hausschwamm." It rots coniferous timber for the most part.

Coniophora puteana (Pl. VIII, figs. 5 and 6) resembles *Merulius lachrymans* in color and general habit of growth. It is less gelatinous, however, and produces no porous strands. In some situations it produces a smooth, very thin, membranaceous layer on the surface of timber; at other times the surface is quite warted or convolute. The danger from the fungus is enhanced by its ability to rot hardwood as well as coniferous timber.

The fact that we are dealing here with two fungi which are known to be widely distributed in lumberyards in the United States, not only in the region covered by this study, but also along the Pacific coast, coupled with our knowledge of the rather common occurrence and seriousness of the same organisms in buildings throughout the same range, is a cause for grave concern on the part of both lumbermen and builders.

Both fungi can readily be introduced into buildings by means of diseased lumber, and it is very probable that at least some of the outbreaks in comparatively new buildings which have come to the attention of the writer can be attributed to this source.

Besides *Merulius lachrymans* and *Coniophora cerebella* the writer has twice encountered another organism of much the same habit of growth and destructiveness. This organism, the identity of which has not yet been determined, was first found in a retail lumberyard in Alabama and later in a cotton warehouse in Mississippi. The owner of the lumberyard had appealed to the writer for assist-



FIG. 36.—The solid type of built-up plank foundation. This permits air circulation beneath the piles in only one direction. The ends of the stock have been painted to prevent checking.

ance in eradicating a very serious infection, so a careful inspection was made at the first opportunity and the organism was found in great abundance in all three of the open storage sheds, where it had destroyed many of the foundation timbers and also passed upward into the stored lumber (Pl. X, figs. 1-4). The first serious infection noted in this yard occurred six years ago, when two carloads of 6 by 6 pine timbers piled in the open yard were so badly decayed to a height of 6 to 8 feet in the piles as to be rendered useless for building purposes. This material was at once disposed of for firewood. Three years later a further outbreak occurred in two of the open storage sheds and in an addition attached to the small office building. During 1913 a serious infection was also found in a third open shed

According to the owners, the immediate loss of this yard in stock and repairs up to October, 1914, was estimated to be between \$1,000 and \$2,000. This represents, however, only the actual loss to the company in lumber, figured at wholesale prices, and labor necessary in making repairs. The potential danger to the consumer using such stock, even though but very slightly infected, would amount to very much more than this sum, for a single stick introduced into each of a number of new buildings would occasion an incalculable amount of damage if such timbers happened to be placed in a moist situation favorable for the further development and spread of the fungus.



FIG. 37.—The latticed type of built-up plank foundations. This is an improvement over the solid type, as it allows better ventilation beneath the piles.

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As soon as the infections were noted as serious, the company attempted eradication and control measures. In the office building the spread of the fungus has been checked by proper ventilation, and in the sheds the same methods are being applied by removing the cinder fills beneath them and raising the foundations to a height of 18 to 24 inches, placing the sills on brick piers. In future repairs the writer has suggested the application of either mercuric chlorid or some creosote compound to the new timbers.

One member of the company so firmly believed that the cinders used for filling about the yard had been highly favorable to the development and spread of the infection that orders were given to remove all of them from beneath the sheds. While it is possible that the infection may have been introduced by means of the cinders, the rapid growth of the fungus was mainly due to poor ventilation. Cinders have been used by a considerable number of other yards with complete satisfaction. Ashes, however, are not to be recommended. There are records in German literature where ashes used for filling between floors to deaden them have been the source of fungous outbreaks. The case of a cotton warehouse investigated by the writer, where pine flooring

laid on flat 2 by 6's resting on ashes was very quickly rotted out by this same fungus (Pl. IX, figs. 3 and 4), likewise offers circumstantial evidence.

The remaining fungus which needs consideration is *Peniophora gigantea* (Fr.) Mass. (Pl. X, figs. 5 and 6). This is a white to pale creamy moldlike growth when immature. When mature it forms a waxy incrustation on the surface of the timber, closely adherent when fresh, but when dry tending to become hard and horny and to curl up at the free edges. This organism is widely distributed, mainly on pine timber, throughout the southern pine belt, and also occurs on conifers in the Rocky Mountain region. In the South it is frequently found in the woods, whence it readily passes to stored lumber. Many lumberyards have been abundantly infected

with it ever since they started in business; so long, in fact, that to sever the attachment would be like losing an old acquaintance. From the southern yards it has been introduced northward and is very conspicuous at certain points along the North Atlantic coast (Pl. III, fig. 7). The timber reaches these points mainly by boat. Close storage of the green or partially dried stock in the hold of a vessel during an ocean voyage of perhaps several weeks usually permits

a vigorous development of the fungus. As a result of this, infections are so abundant in some of the North Atlantic yards that one would have difficulty in finding any clean material whatever.

It is fortunate that the organism does not approach in destructiveness such forms as have been previously described, else many lumberyards would be doomed immediately. It is a wood-destroying fungus, however, which limits its action to the sapwood. Although the deterioration is comparatively slow, it does weaken the timber to a considerable extent and should be guarded against along with the more dangerous fungi.



FIG. 38.—Concrete foundations in the retail yard in Alabama shown in figure 15.

WOOD PRESERVATIVES IN THE LUMBERYARD.

Aside from the advisability of preserving permanent structures in the lumberyard by the use of antiseptics applied to or injected into the wood, the question of preserving the lumber itself from incipient infection until it reaches the consumer is one which merits careful thought. During the past decade the use of soda (sodium carbonate or bicarbonate) dips to prevent blue stain has become general throughout the southern pine belt. Within the writer's own experience, sawmill men who in 1909 scoffed at such a measure had within three or four years fallen in with the procession and were enthusiastic advocates of it. As yet the idea of dipping the lumber to prevent infection from true wood-rotting fungi has not been con-

sidered by the lumbermen. The soda dip is not sufficient to accomplish the desired end, so we must look elsewhere for a suitable preservative. Mercuric chlorid is a hazardous thing to use on general stock, on account of its extremely poisonous nature, but is very efficient and safe enough for special purposes. Zinc chlorid is objectionable mainly on account of its capacity to attract moisture. Of the remaining colorless salts in use for wood



FIG. 39.—Broken foundations, a result brought about by not reinforcing the concrete. The company later embedded some old 20-pound steel rails in the concrete near the top.

preservation sodium fluorid or some colorless salt of hydrofluoric acid would probably meet the needs of the situation very well. Sodium fluorid is highly toxic to fungi, but can be handled by workmen with no danger of poisoning. It is colorless, easily soluble, and can be handled in any way that the soda dip can. It is more effective than soda and so could readily be substituted for it, thus protecting against both the blue stain and the wood-rotting fungi by a single treatment.

This whole feature of dipping lumber in this way to keep it in a clean condition for the consumer must necessarily involve the close cooperation of millmen, wholesale men, and retailers. The millman may feel indifferent to the proposition, claiming that the de-

terioration in his yard is not sufficient to warrant it. But this is not merely a mill problem; it is a lumber problem which involves the entire industry and the cooperation of all its members. Even though the mill operator may not in many cases suffer personal monetary loss, still he is often a contributing factor in the losses borne by the retailer and consumer, for incipient decay originating in mill yards and passed over to retail yards may during the later period of storage progress rapidly.

The added cost of treatment would be insignificant in comparison with the benefit derived, and if the lumber trade would take the trouble to explain the benefits to the consumer the slight additional expense would in all probability readily be met by him. Even though it should not be deemed feasible to add the cost of treatment to the finished product, the direct saving accruing to the lumber dealer himself should warrant the expense. It is imperative that something be done by the lumberman to put his product on a more favorable competing basis with other structural materials if he is to safeguard the lumber business for the future.

Another line of endeavor which would reflect favorably on the whole industry is for the lumber dealer to carry in stock, or at least be in a position to produce on order, timber thoroughly treated for construction purposes by certain of the well-known preservative processes. The wood-preserving industry to-day is primarily conducted for the benefit of the heavy consumer. The builder who may need only small quantities of treated stock to place where decay is most likely to occur in his structure is usually unable to obtain it except at prohibitive cost.

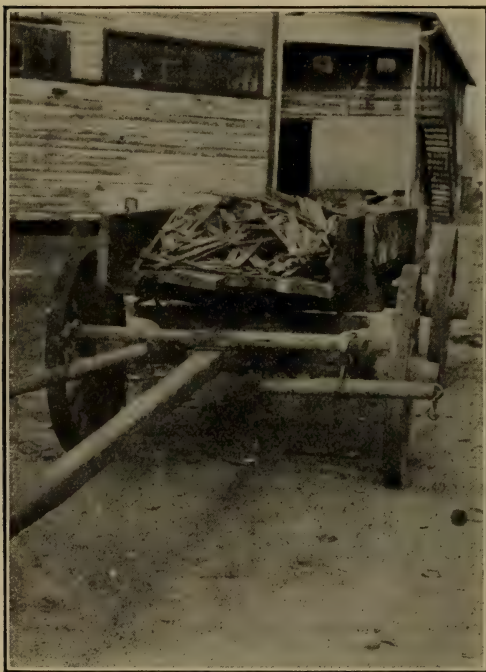
The preservative treatment of timber is no magic process and involves no heavy expenditures for necessary apparatus, especially in connection with the simpler methods of treatment. The kyaniz-



P104F

FIG. 40.—A southern retail yard, showing a most insanitary way of handling lumber. Structural timbers should never be thrown promiscuously about on the ground in this manner to become infected with wood-destroying fungi.

ing process consists merely in the immersion of the timber in an open wood or concrete tank containing a solution of mercuric chlorid. Any of the other water-soluble salts could be applied in the same way. Creosotes and carbolineums can also be applied in this manner. While in many cases the amount of preservative which can be injected in this way would not be sufficient to fully protect timber in direct contact with the ground, in most cases where treatment is indicated in buildings it would be sufficient. Such treatments could be carried out by any one at any point, and the local treatment of timber would probably be cheaper than when done at a distant centralized plant. In the East, such a local method of treatment is



P106F

FIG. 41.—Wagon loaded with fragments of lumber to be hauled away. This is the highly commendable practice by which one lumber company keeps its yard clear of débris.

being carried out by at least two lumber dealers within the writer's acquaintance.

If treated timber were put on the local markets as a standardized product, as readily available to the man who needs 100 feet as to him who uses it by the 100,000 feet, the favorable results experienced by the public in the use of the treated product would in the course of a few years create a demand and be a stepping stone toward a more profitable lumber industry.

BRANDING STRUCTURAL TIMBER.

The discussion now leads us to a consideration of the advantages of branding

timber in order to safeguard both the reputable timber producer and the consumer. Such a practice is of particular value in the case of dimension timbers where a standardized uniform product, graded particularly on strength and durability, must be supplied. It is customary at the present time to so brand longleaf pine for export, but the practice is very little followed for the interior trade. Some few retailers stencil their name or brand on certain stock, but this is with them more a matter of advertising than a guaranty of quality,

and this must necessarily be the case until a standard and succinct set of grading rules is put into practice by all dealers.

Branding not only puts the company's guaranty of quality behind the product, but indicates as well the kind of timber supplied. Thus, for example, an operator in Douglas fir and western white pine in Idaho could not then possibly confuse his product with southern pine or eastern pine when it reaches the eastern market. For the architect it is very essential to know that the kind of timber he receives accords with the specifications.

The biggest and most enduring reputations in any line of industrial activity are based on the best type of service. When the lumberman who has the highest desire for good service throws his product promiscuously on the market with the lower grade materials, he is at the same time throwing away an industrial asset of no doubtful value. This will become more and more the case as the building public wakes up to the dangers lurking in the use of inferior or fungus-infected timber.

The timber of the United States is a national asset in which the citizens have a certain vested interest which calls for the best utilization possible. The lumberman as guardian of these interests certainly owes to the public no less than his best efforts to convert the forest into a finished product which shall ultimately reach the consumer in prime condition.

CONCLUSIONS.

Improvement of lumber storage conditions can be brought about by modifying present insanitary practices along the following lines:

(1) Strong efforts should be made to store the product on well-drained ground, removed from the possible dangers of floods, high tides, and standing water.

(2) All rotting debris scattered about yards should be collected and burned, no matter whether it be decayed foundation and tramway timbers or stored lumber which has become infected. In the case of yards already filled in to considerable depths with sawdust and other woody debris the situation can be improved by a heavy surfacing with soil, slag, or similar material.

(3) More attention should be given to the foundations of lumber piles in order to insure freedom from decay and better ventilation beneath the stacks. In humid regions the stock should not be piled less than 18 to 24 inches from the ground. Wood blocking used in direct contact with wet ground should be protected by the application of creosote or other antiseptic oils or else replaced by concrete, brick, or other durable materials. Treated horizontal skid timbers would also be highly advantageous, for stock should never be piled in direct contact with diseased timber.

(4) Instead of throwing the "stickers" about on the ground, to become infected, they should be handled carefully and when not in use piled on sound foundations and kept dry as far as possible. If resinous pine or the heartwood of such durable species as white oak or red gum be employed, the danger of possible infection will be greatly decreased.

(5) In most regions lumber should not be close piled in the open, but should be "stuck" with crossers at least 1 inch thick. Lateral spacing is also very desirable. Roofing the piles should not be neglected.

(6) In storage sheds the necessity for piling higher from the ground is very apparent in many cases. The same remedies apply here as for pile foundations in the open. The sheds should be tightly roofed and the siding should not be run down below the bottom of the foundation sills. Free air circulation should be allowed from all sides beneath the inclosure. Only thoroughly dry stock should be stored in close piles under cover.

(7) Should fungous outbreaks occur in storage sheds not constructed to meet sanitary needs the infected foundation timbers should all be torn out and replaced with wood soaked in an antiseptic solution or by concrete or brick. In all cases the new foundations should be so constructed as to keep the lumber well off the ground, and the soil and timber immediately adjoining the infected area should be sprayed or painted with an antiseptic solution of a water-soluble salt, like sodium fluorid, mercuric chlorid, zinc chlorid, or copper sulphate.

Stock which has become infected should never be sold for permanent construction purposes. The placing of such infected stock in buildings may lead to disastrous results, for which the dealer may be held responsible.

(8) The dipping of yard stock in a water solution of sodium fluorid appears advisable from the standpoint of preventing blue stain and incipient infection with wood-destroying fungi during storage.

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PROFESSIONAL PAPER

June 12, 1918

FOREST DISEASE SURVEYS.

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INTRODUCTION.

The National Forests are administered with the expectation of their becoming self-supporting through the medium of returns from such activities as timber sales, grazing, and special-use privileges. Of these operations, that of the sale of timber is, in the National Forests of the northwestern United States, unquestionably of the greatest importance in respect to paying the expense of administering the forest. In district No. 1 in the year 1916 the total receipts from timber sales equaled \$439,880 and grazing \$50,836. These figures show the relation between the two incomes derived from the principal forest activities of this district. Some few of the forests have already attained a position of self-support. One forest in particular is reported to have outdone all expectations and in so doing has aided in the administration of forests whose incomes have been less than their expenses. In such self-supporting forests it is always found that a ready market and available timber supply have resulted in a maximum of timber sales. It is, then, a foregone conclusion that timber sales in the National Forests of the Northwest are the mainstay of a self-supporting policy and that all data of value to timber-sale operations are bound to be of value in their successful supervision. The data and recommendations included in this paper are based on conditions prevalent in district No. 1 of the United States Forest Service.

OBJECT OF FOREST DISEASE SURVEYS.

Timber surveys have as their prime object, the gathering of such data upon proposed sales areas as will be of use in the appraisal and administration of the sales, and it is this survey which makes the sale possible. The collection of valuable data on the board-feet con-

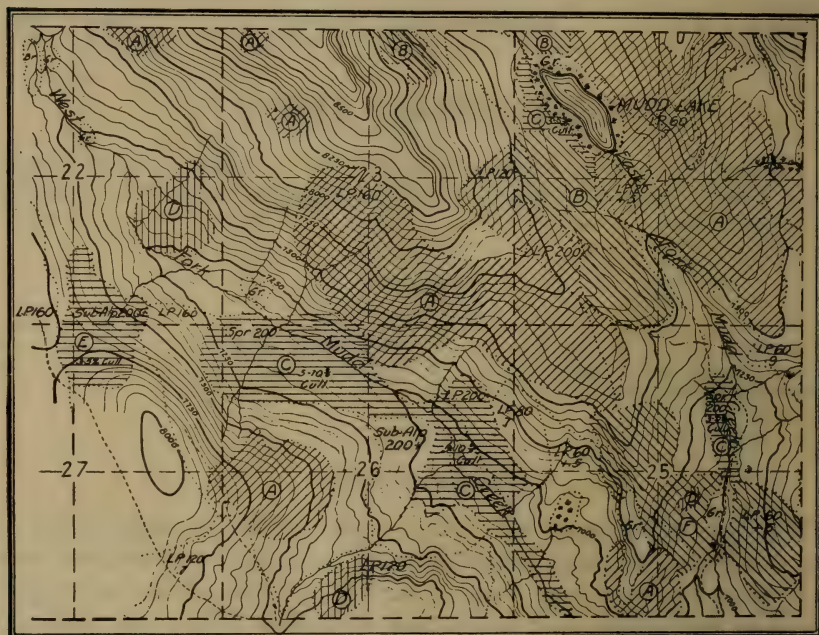


FIG. 1.—Pathological map of sections 22, 23, 24, 25, 26, and 27, T. 2 N., R. 15 W., the Big Hole area, based upon the map of the timber survey of that area in the Deerlodge National Forest, Mont., showing timbered areas infected with disease. The rot percentages are indicated for heart-rot (*Trametes pini* (Brot.) Fr.) and butt-rot (*Polyporus schweinitzii* Fr.) only. Crosshatching indicates infection areas. Other symbols on the map are part of the Forest Service map legend, such as Spr. 200, which indicates Engelmann spruce, 200-year age class; L. P. 60, 0.7 equals lodgepole pine 60-year age class, density 0.7; Gr. equals grassland; Br. equals brush. A, Pine rust (*Cronartium coleosporioides* (D. and H.) Arthur), gall and blister forms, on lodgepole pine (*Pinus contorta*); B, smelter-smoke injury, principally of alpine fir (*Abies lasiocarpa*) and Douglas fir (*Pseudotsuga taxifolia*); C, honeycomb rot (*Trametes pini* (Brot.) Fr.), principally on Engelmann spruce (*Picea engelmanni*); D, porcupine injury—peeling of bark and girdling of lodgepole pine; E, cubical butt-rot (*Polyporus schweinitzii* Fr.) on lodgepole pine and white-bark pine (*Pinus albicaulis*); F, mistletoe (*Razoumofskyia americana* (Nutt.) Kuntze) on lodgepole pine.

tents of the stand, cull percentages, forest types, age classes, topography, and logging factors is followed by an accurate map portraying the topography, types, density; age classes, and timber estimates. A careful stumpage appraisal of the area based upon these available data and upon the various economic and topographic factors forms the final step before contracts are let.

In most cases the appraisal of a timber-sale area is based somewhat low in respect to the total feet board measure of sound material, principally on account of the unknown amount of defect or rot to be encountered and sometimes partially for other causes, foremost of which is the desire to prevent overestimation.

In timber surveys the estimating of timber is performed by members of the party who have been trained to estimate stands of varying mixtures, age, and soundness and who are thoroughly capable of



FIG. 2.—Fruiting bodies of *Trametes pini* on lodgepole pine. Notice the swelling of the trunk where the fruiting bodies are attached. (Photographed by G. G. Hedgcock.)

judging the board-feet contents of trees within reasonable limits of error. The addition to the party of an expert cruiser has been made as a means of aiding the estimators in this work and checking their results. The determination of the correct cull percentage due to rot is the aim of this arrangement in the crew.

In certain types and ages of stand the estimate may come close to the true scale, but, again, too small a percentage is deducted for cull due to rot, and consequently the estimate runs too high. A sale contractor figuring possibly on a conservative margin and accepting the

estimate at its face value may find upon cutting the stand that a great deal more rot is encountered than was expected. This fact alone could easily result in the logging operation turning out a loss instead of a profit, especially if the logging chance is not a favorable one. Such failures doubtless do not encourage the undertaking of further contracts, and fewer timber sales are the result. This has its ultimate effect upon the forest as a whole in an economic way.

Recent studies made of the rots occurring¹ in forest trees have given information concerning the amount of decay prevalent in different age classes and in different sites for a particular species of tree. These studies have indicated that the decay in a tree or a stand varies with such factors as age of stand, site, density, injuries, and moisture relations. Such being the case, a disease survey of the sales areas made either as a separate pathological survey or in conjunc-



FIG. 3.—Typical rot of *Trametes pini* (honeycomb rot) in white pine.

tion with the usual timber surveys would prove of immense value in a closer estimate of the sound board-feet contents of the stands. A disease survey in conjunction with the timber-survey work would no doubt be the more feasible plan of the two, since it would require no additional men for the crews and should not appreciably affect the cost per acre. All that would be required in order to secure the disease data in more accurate form is the training of one of the members of each unit crew in the proper methods by which the various pathological determinations are made. This would mean the ability to judge more accurately the cull percentage due to rot and the ability to recognize all the outward indications of decay as well as the principal fungi attacking forest trees. Preferably, the estimator should be the one selected to assume this duty, as it is his individual work which determines the total estimate and the cull percentage of the stand.

¹ Meinecke, E. P. Forest pathology in forest regulation. U. S. Dept. Agr. Bul. 275, 62 p. 1916.

The topographer, while sketching in the type lines and indicating the age class divisions, can at the same time indicate the boundaries



FIG. 4.—Typical rot of the Indian-paint fungus on *Abies grandis*. Note the spines on the fruiting body of the fungus. (Photographed by G. G. Hedgecock.)

of the heavier disease infections and also pencil in the cull percentages. In this way a pathological map¹ can be secured for the area

¹ Weir, J. R. Some suggestions on the control of mistletoe in the National Forests of the Northwest. In *Forestry Quart.*, v. 14, no. 4, p. 567-577. 1916.

surveyed, and along with careful notes of the estimator upon the diseased areas and upon data secured by means of a few small sample



FIG. 5.—*Polyporus schweinitzii*, the velvet-top fungus.



FIG. 6.—Typical rot of the velvet-top fungus in the end of a white-pine log. Note the cubical character of the rot.

plats a very close estimate of the cull percentage to be expected can be had. Checks can be made upon the estimator's work by the expert cruiser. Members of the Office of Investigations in Forest Pathology can render excellent service by aiding each unit crew in the field in becoming familiar with the various diseases and their causes.

If properly adjusted, this work would cause no variations in the amount of line run per day by the unit crews. The junior

writer has tested and proved this assertion in practice while employed by the Forest Service on the Big Hole timber survey made in 1914 in the Deerlodge National Forest of Montana. From the data thus collected pathological maps were made, giving in colors the areas of the stand infected, respectively, with the pine rust (*Cronartium coleosporioides* (D. and H.) Arthur), both gall and blister forms, mistletoe (*Razoumofskya americana* (Nutt.) Kuntze), heart-rots (*Trametes pini* (Brot.) Fr. and *Polyporus schweinitzii* Fr.), and various other diseases (fig. 1). Careful notes

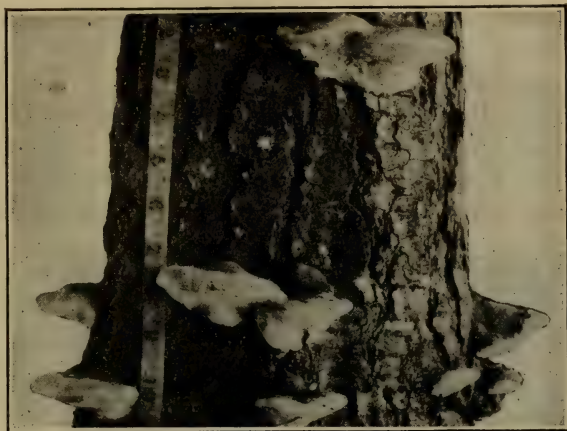


FIG. 7.—*Fomes pinicola*, the red-belt *Fomes* growing on grand fir.

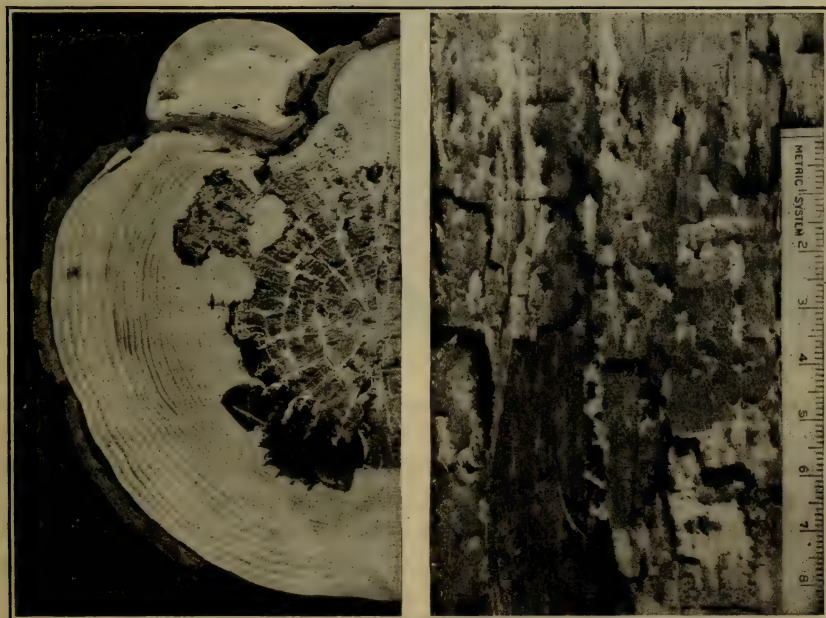


FIG. 8.—Typical rot of the red-belt *Fomes* in grand fir; cross and tangential sections. Note the strands of white felty masses (mycelium) throughout the rotted areas.

were taken as to the percentage of infection in each case, and a closer estimate of the amount of cull was made possible. In one particular

case an estimator wished to give a full estimate of a stand of white-bark pine (*Pinus albicaulis* Engelm.) growing upon a flat ridge. The trees of this stand upon closer examination were found to be almost universally heart-rotted with *Polyporus schweinitzii* for a distance of 5 to 12 feet up from the base. The trees were fairly large and if sound would have made excellent stull material, the chief product in the Big Hole Basin region of Montana. Giving a full estimate to these trees would have meant a serious overestimation of the stand, since it was finally estimated that about 40 to 50 per cent by volume was cull due to the heart-rot. Fruiting bodies of the causal fungus



FIG. 9.—*Polyporus sulphureus*, sulphur fungus, at base of larch.

almost hidden in the débris at the base of the trees gave the determining clue, and soundings upon the trunk followed by notching completed the determination.

There has always been a serious need for some method by which a fairly accurate estimate can be made of the rate of decay of a stand of timber.

Good results as to the probable cull percentage to be expected from rot upon a certain stand have been secured by expert and experienced cruisers and appraisers. Timber surveys have in most cases placed the estimates of sound timber within a reasonable limit of error; but

evidently no attempt has ever been made to secure a more accurate result in respect to the cull in a stand due to rot other than those results secured by ocular estimates. Occasionally in the administration of National Forests the question arises concerning the probable rate of increase in rot per annum in a certain stand of timber. The resultant decision as to the time of disposal of the timber hanging in the balance depends upon the amount of accurate knowledge and the data at hand regarding the decay in the trees. If proper and sufficient data are secured, these will furnish the total volume and the total volume of rot for the stand in question. With these as a

basis and figuring in all the economic and silvicultural factors concerned, a cutting age can be computed, aimed to secure the greatest amount of sound material at a minimum of cost. No definite rule can be given as to the value of the ratio between the total volume and the volume of rot required in determining the cutting age. Too many factors are concerned even to generalize, and each stand must be judged according to the conditions present at the time it is under consideration. But it is unquestionably true that data giving the relation between the sound and the decay increment in a stand, as well as giving an approximation of the rate of increase in decay to be expected, will aid greatly in solving the question of the proper cutting age for that stand.

Forest management of this kind can be practiced to a profitable end provided intensive methods are employed in making a special disease survey of the area in question. Surely this would be a step toward more intensive and more economic forest management and would aid in solving many of the perplexing problems hinging upon the decay in timber. The cost of such a survey would not be prohibitive by any means, even in case the stand

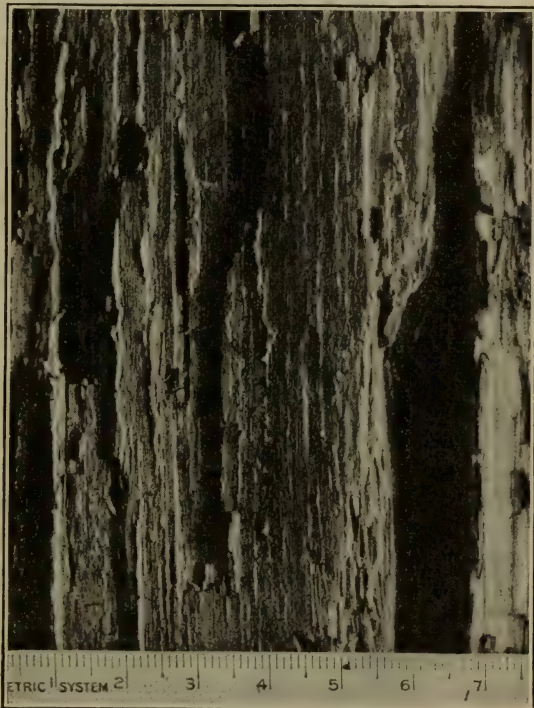


FIG. 10.—Typical rot of the sulphur fungus in larch.

were composed of more than one age class, since sample plats of small dimensions could be successfully used in securing the necessary data upon the decay. To supplement these and aid in the diagnosis of the stand, such available data previously secured for similar tree species, age classes, sites, etc., could be used to advantage.

Aside from the advantage secured in arriving at a more accurate rot percentage for a stand, a disease survey accompanied by a pathological map would be extremely useful after the sales are closed, the brush burned, and preparations made for the reforestation of the cut-over area. Looking into the future is the forester's basic prin-

ciple, and whenever forestation of an area either by natural or artificial reproduction is contemplated it would be extremely unwise to overlook the risks to the young growth incurred by possible disease. A pathological map would serve to give the previous location of diseased trees, as well as the location of diseased uncut areas surrounding the sale area and the localities and sites where diseases seem most prevalent, and would also serve to indicate whether the seed trees left, if any, were of a group which was heavily diseased or not. Diseased trees of any kind left as seed trees or otherwise on or surrounding a cut-over area always act as distributing points of disease to the young growth occupying the near-by areas.



FIG. 11.—*Fomes officinalis*, chalk fungus, on western larch.

For this reason attention has recently been centered upon the introduction and strict enforcement of sanitation clauses in all timber-sale operations.¹ These clauses include the removal by burning of all heavily infected standing trees and all cull material left on the area and strongly advise the use of healthy trees as seed trees instead of diseased ones.

For the same reason as given above for the protection of young growth in cut-over areas, a disease survey is even more necessary

upon proposed nursery sites, present nursery sites, and all plantation sites. Wherever young trees are grown in close proximity to heavily diseased native trees or alternate hosts of forest-tree rusts there

¹ Meinecke, E. P. Forest-tree diseases common in California and Nevada. U. S. Forest Service Manual, p. 62. Washington, D. C. 1914.

Weir, J. R. Some factors governing the trend and practice of forest sanitation. *In* Forestry Quart., v. 13, no. 4, p. 489. 1915.

Meinecke, E. P. Forest pathology in forest regulation. U. S. Dept. Agr. Bul. 275, 62 p. 1916.

Weir, J. R. Larch mistletoe: Some economic considerations of its injurious effects. U. S. Dept. Agr. Bul. 317, p. 24. 1916.

Weir, J. R. Mistletoe injury to conifers in the Northwest. U. S. Dept. Agr. Bul. 360, p. 33-37. 1916.

always remains a great danger of infection spreading to the young stock, with consequent loss. This has been shown in several recent cases where forest nurseries were located in close proximity to diseased trees and alternate hosts. At the forest nursery at Haugan,

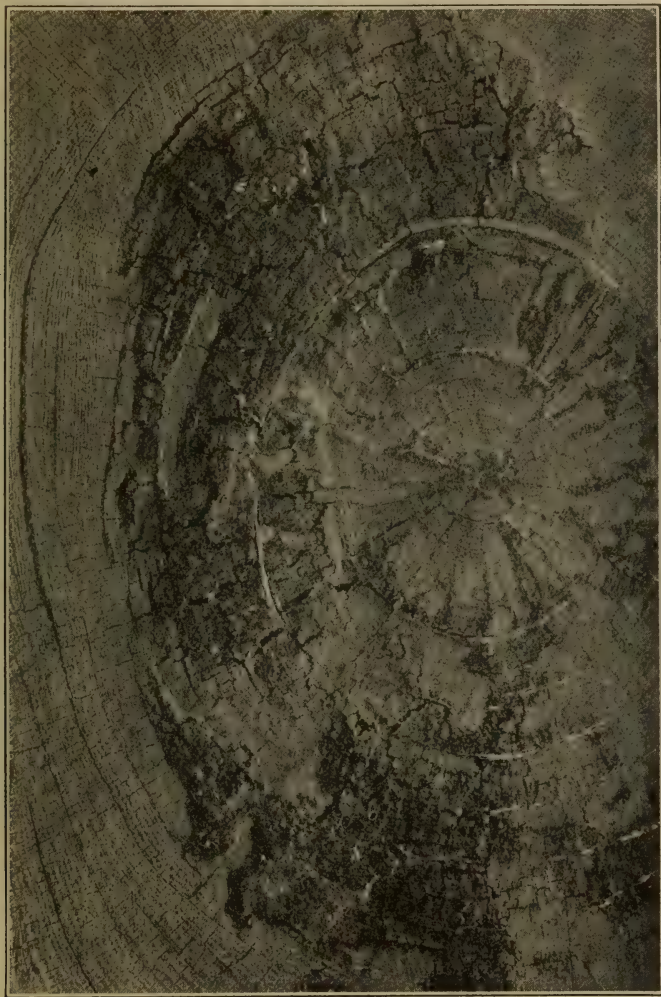


FIG. 12.—*Fomes officinalis*, chalk fungus, showing typical rot in lodgepole pine. Note the white mycelium in the cracks. (Photographed by G. G. Hedgcock.)

Mont., yellow-pine seedlings became seriously infected with *Cronartium coleosporioides* (*Peridermium filamentosum* Pk.). The disease was transmitted by means of the alternate form of the rust occurring on the Indian paintbrush (*Castilleja miniata* Dougl.), which was found growing at the very edge of the nursery beds.¹ A survey of

¹ Weir, J. R., and Hubert, E. E. A serious disease in forest nurseries caused by *Peridermium filamentosum*. In Jour. Agr. Research, v. 5, no. 17, p. 781-785. 1916.

the site, made at the time the nursery was contemplated, would no doubt have resulted in the discovery of the same rust upon the nearby lodgepole pines as well as upon the Indian paintbrush plants, and future losses would have been prevented. The infection with a needle fungus¹ of Douglas fir seedlings at the Boulder nursery, Boulder, Mont., and the occurrence of a mistletoe upon the seedlings² were due to these diseases being extremely prevalent upon the surrounding native trees of this species. The young and crowded seedlings became ready hosts for the fungus, and considerable damage resulted.

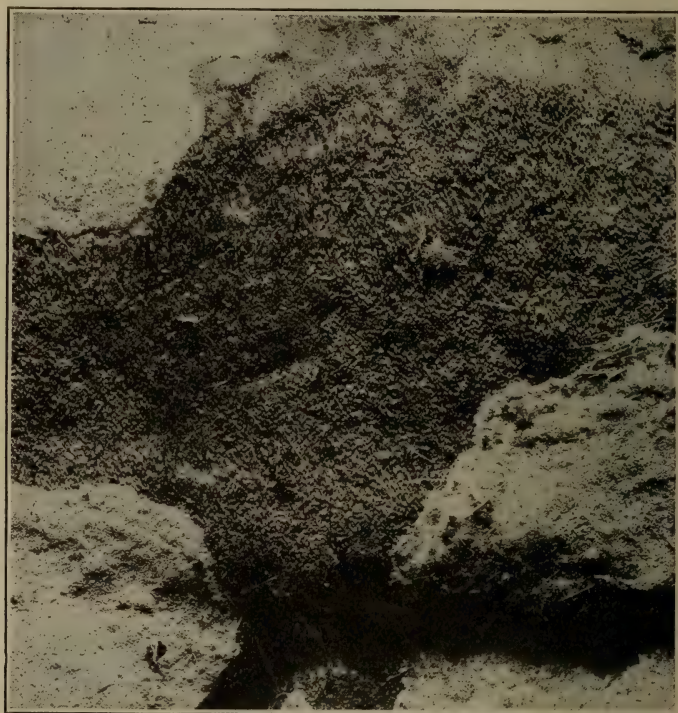


FIG. 13.—*Poria weirii*, brown-cedar poria. Fruiting surface.

In the State nursery at Roscommon, Mich.,³ a similar proximity of native infected trees and susceptible nursery stock resulted in a serious epidemic.

No less care should be taken with proposed plantation sites upon burned-over or cut-over areas. A disease survey should be made

¹ Weir, J. R. A needle blight of the Douglas fir. In Jour. Agr. Research, v. 10, no. 2, p. 99-103, 3 figs. 1917.

² Weir, J. R. Mistletoe injury to conifers in the Northwest. U. S. Dept. Agr. Bul. 360, p. 35. 1916.

³ Kaufman, C. H., and Mains, E. B. An epidemic of *Cronartium comptoniae* at the Roscommon State Nurseries. In 17th Ann. Rpt. Mich. Acad. Sci., 1915, p. 188-189. 1916.

upon all such areas in which the newly transplanted seedlings are subject to infection by fungi or mistletoe. Many of the plantation sites of this region are located upon burned-over areas, and the majority of these are so badly fire swept that very little has been left in the form of coniferous hosts for forest-tree diseases. However, to review the succession of plant life on a burned-over area, after a fire which has been sufficiently intense to destroy every vestige of humus and litter, is to find that the alternative hosts of some viru-

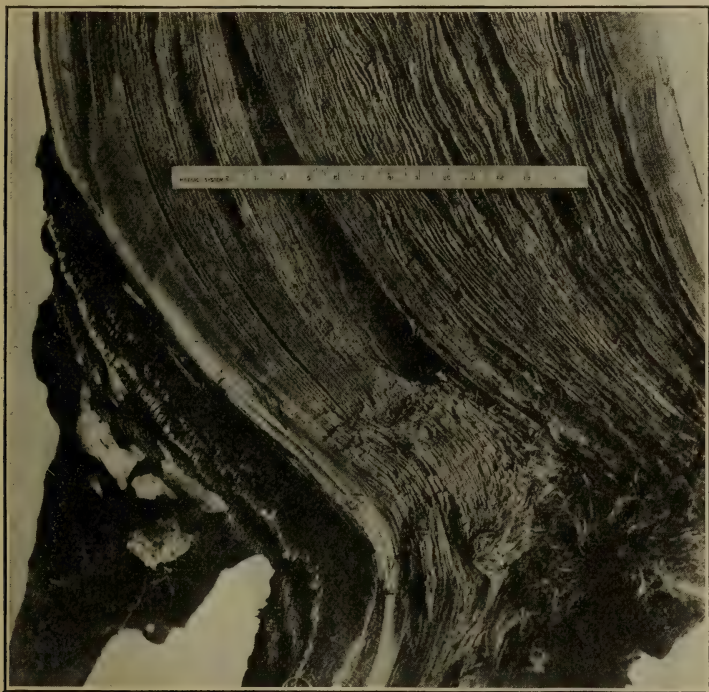


FIG. 14.—Typical rot of brown-cedar poria in butt and roots of cedar. Note the laminations of the rot and (on the left) the fruiting of the fungus.

lent needle or twig diseases have invariably appeared. In many cases the new plant succession carries with it alternate host plants of important forest-tree rusts which soon bear their parasitic fungi, and some of these are found to menace the young tree growth upon the area. A disease survey of such a site is very necessary, especially if the site is to be used as a plantation area for susceptible seedlings.

DISEASE-SURVEY METHODS.

The most practicable methods only are to be applied by unit crews in gathering forest-disease data. These methods should be applied with a reasonable knowledge of the principal destructive disease

agencies, such as fungi, mistletoes, smoke, frost, wind, and snow injury, their outward recognition, and their possible and actual damage to the trees. Sample plats of small dimensions can often be resorted to in order to ascertain the extent of a heart-rot in a certain age class. Borings can be made with an increment borer on a few sample trees and thus the kind of rot and in the case of butt rots the extent of decay can be determined. Soundings on the trunk, the presence of sporophores, the number of dead branches or in-

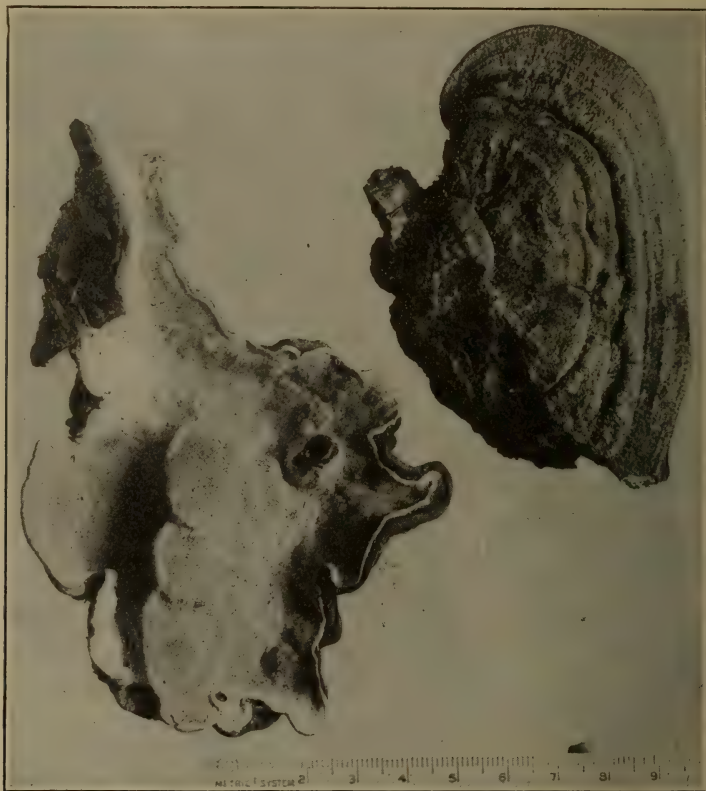


FIG. 15.—*Fomes annosus*, root Fomes. Typical fruiting bodies.

juries, and the presence of the unmistakable swells and pitch flows occurring at old branch whorls all aid in the determination of the presence and extent of decay within a tree. The amount of decay bears a certain relation to the age of a stand, becoming greater as the stand grows older.

Owing to this fact, a table similar to the cull table given on page 25 of the Reconnaissance Manual of District 1, United States Forest Service, but giving the rot percentage only for a range of age classes for each tree species would prove of value in judging the decay in the stand. Such a table would give a range in rot percentages to be

found in a certain age class, a certain site (slope and bottom) for a given tree species for a given kind of rot, and would be compiled from intensive field studies made upon felled trees. It would properly be termed a "table of rot percentages" and would be used by the estimator of each unit crew to determine the rot percentages for each type of forest encountered. Further deductions for other defects could then be estimated and the total cull percentage secured by the addition of the rot percentage. In conjunction therewith, another table giving (1) the class of defect, (2) common name of the defect, (3) the fungus causing it, (4) the various tree species affected, (5) the general external and internal characteristics of the defects, and (6) the average extent of the rots and the general form of the rot within the tree would be of great service to the estimator. Such a table prepared from field data secured during the past three seasons is here submitted. (Table I; figs. 2 to 23.)

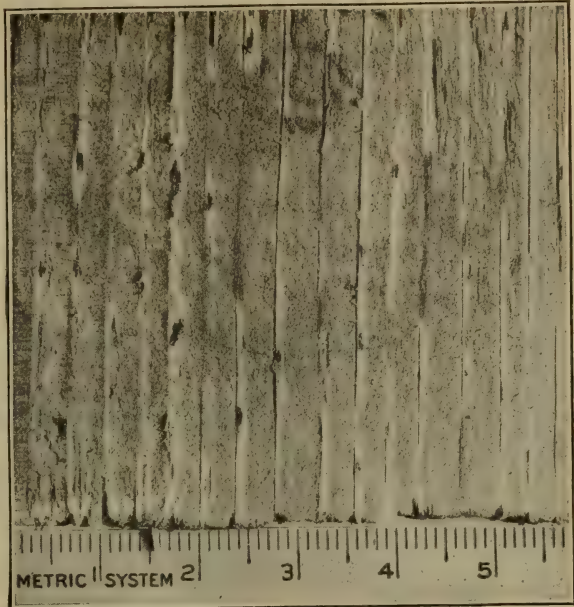


FIG. 16.—Typical rot of the root Fomes in grand fir. Note the black dots in the white areas.



FIG. 17.—*Pholiota adiposa*, the scaly *Pholiota*. (After Freeman.)

TABLE I.—Decay determinations for standing trees for the use of estimators and marking officers.

(Abbreviations: AF=alpine fir, C=western red cedar, DF=Douglas fir, ES=Engelmann spruce, GF=grand fir, I=western larch, LP=limber pine, LPP=lodgepole pine, MH=mountain hemlock, WB=white-bark pine, WH=western hemlock, WP=western white pine, YP=western yellow pine.)

Class of defect.	Common name for the defect.	Causal parasite (scientific and common names).	Trees generally attacked.	External signs of decay or defect.	Characteristics of decay.
Trunk-rot, occasionally acting as butt-rot; generally patchy.	Honeycomb rot. (fig. 3).	Trametes pini, ring-scale fungus (fig. 2).	WP, YP, LPP, WBP, LP, ES, WH, MH, AF, GF, C, DF, and L.	Typical fruiting bodies of the fungus on the tree; indications at old branch whorls, either by swellings or by brownish punky substance that fruiting bodies have dropped off; soundings made on the trunk to detect hollowness or punkiness, indicating decay; many injuries of various kinds; presence of typical rot; catclaws at the base induce the butt-rot form.	Heart-rot in resinous trees: heart-rot or sap-rot in trees of little or no resin; in early stages, reddish color in split section, with small or large white elliptical patches, punky, soft, brown (discolored); in cross section, small white patches mingled with pitted areas and in advanced stages ring sealed, annual rings separated; delignifying rot, viz., converting wood to cellulose; white-rot; conical in both directions from the area of greatest decay in trunk; as butt-rot, conical, tapering at upper limits; often as patchy areas not uniformly attacking the heart-wood.
Trunk-rot (uniform, circular); entire tree.	Stringy brown-rot (fig. 4).	Echinodontium tinctorium, Indian-paint fungus (fig. 4).	AF, GF, WH, and MH.	Typical fruiting bodies of the fungus on the tree; indications at branch whorls, either by swellings or by deep rusty-red punk knots, that fruiting bodies have dropped off; large number of dead branch stubs, accompanied by pronounced swellings at whorls; deep rusty-red color in old branch stubs; soundings made on the trunk; many injuries, such as logging scars, fire scars, blazes, etc., presence of typical rot.	Uniform heart-rot (confined to given tree species almost entirely); in early stages, wood spongy, yellow stained; typical stage, soft, stringy, brownish to rusty red in color, knots showing a deep rusty-red color; saved surface (cross-section), pitted, broken, and stringy, with reddish brown discolorations, often hollow rotted; carbonizing rot, viz., reducing cellulose, producing dark-coored decay; conical in both directions from the area of greatest decay; very uniform in occupying most or all of the heartwood.
Butt-rot, from roots up to 12 feet into first log (uniform, circular); usually 5 to 6 feet up.	Cubical butt-rot (fig. 6).	Polyporus schweinitzii, velvet-top fungus (fig. 5).	WP, YP, LPP, WBP, LP, DF, GF, AF, and C.	Typical fruiting bodies of the fungus on the ground near the tree (nearly always partly covered by débris), sometimes found as bracket fungus issuing from injuries at the base of the tree (never high up on the trunk); indications of brown-rot in the exposed roots; soundings on the basal portion of the tree and on exposed roots; presence of typical rot.	Uniform heart-rot of butt of tree (also enters roots); in early stages, light reddish brown; typical stage, reddish brown; pronouncedly cubical, crumbly, and brittle when dry; occasionally with thin resinous crusts of white feltlike material (mycelium); odor of turpentine; carbonizing rot; conical from the base of the tree upward; uniform, usually not advancing beyond first log.

Trunk-rot (uniform, circular).	Brown crumbly rot, (fig. 8).	Fomes pinicola, red-belt fungus (fig. 7).	All the important conifers, principally L, WH, MH, AF, and GF.	Typical fruiting bodies of the fungus on the tree; typical rot at old branch stubs; soundings made on the trunk; presence of typical rot.	(1)
Do.....	Reddish brown heart-rot (fig. 10).	Polyporus sulphureus, sulphur fungus (fig. 9).	Almost all important conifers, principally L, DF, YP, ES, and WP.	Typical fruiting bodies of the fungus on the tree; soundings made on the trunk; presence of typical rot.	Uniform heart-rot; in early stages, light brown, typical stage, dark reddish brown; brittle when dry, crumbly (not pronouncedly cubical), with thick felty mycelial masses in clefts, star shaped in cross section; carbonizing rot; conical, uniform.
Trunk-rot (entire tree); in YP occupies upper part of the tree.	Reddish brown heart-rot (fig. 12).	Fomes officinalis, chalk fungus (fig. 11).	All important conifers, principally L, YP, DF, and ES.	Typical fruiting bodies of the fungus on the tree (the principal means of distinction between rots of this species and that of the sulphur fungus); soundings made on the trunk; presence of typical rot.	Uniform heart-rot; in early stages, light brown; typical stage, dark reddish brown, brittle, dry, crumbly, with thin felty mycelial masses in clefts; carbonizing rot; conical, uniform.
Butt-rot; from roots up to 8 feet into butt log.	Yellow laminated rot (fig. 14).	Poria veltrii, brown cedar poria (fig. 13).	C and eastern arbor vitae.	Typical fruiting bodies of the fungus on the tree (in the root crotches often cementing the forest debris about the roots into a punky mass); soundings at the base of the tree and on exposed root spurs.	Uniform heart-rot; light-yellow color; decayed spring wood separating annual rings in advanced stages, brown felty mycel; lum between layers; carbonizing rot; conical, uniform.
Butt-rot (uniform, circular); from roots up to 8 feet into butt log.	White spongy rot (fig. 16).	Fomes annosus, root Fomes (fig. 15).	ES, WP, YP, LPP, WBP, LP, WH, MH, AF, GF, C, DF, and L.	Typical fruiting bodies of the fungus in the root crotches, usually covered up; resin flow at the base of the tree or roots; soundings at the base of the tree and on exposed roots.	(2)
Trunk-rot (uniform, circular).	Yellow heart-rot (fig. 18).	Pholiota adiposa, scaly pholiota (fig. 17).	GF, AF, WH, MH, ES, and WP.	Typical fruiting bodies of the fungus on the tree; soundings made on trunk; presence of typical rot.	(3)
Burl injury.....	Mistletoe buris (fig. 20).	Razumovskya spp., mistletoe (fig. 19).	YP, LPP, WH, MH, L, and DF.	Typical mistletoe plants upon branches and twigs; witches' brooms; conspicuous swellings on the trunk or branches.	When fruiting stage is inconspicuous during May to August, a light chipping of bark on swellings and cankers will disclose orange-yellow powder or fruiting layer.
Galls and cankers.....	Pine cankers (fig. 23).	Cronartium coleosporioides, gall and blister forms: Cronartium comandrae, pine rust (figs. 21 and 22).	YP and LPP.....	Presence (during months of May to August) of orange-yellow, powdery masses on pronounced swellings; catfaces or cankers of trunk and branches, absence of mistletoe plant upon galls and cankers.	

¹ Uniform heart-rot, found principally in dead standing and down timber; occasionally acting as heart-rot in living trees by gaining entrance through injuries; in early stages, rot light brown; typical stage, reddish brown, cubical, crumbly and brittle when dry, white feltlike layers of mycelium between cubical patches; felt patches larger, thicker and nonresinous as compared to those of the velvet-top fungus; carbonizing rot; conical, uniform.

² Uniform sap-rot and heart-rot of butt; in early stages, ranging from lilac to reddish in color; typical stage, whitish areas separated by smaller areas of sound wood (not pronouncedly pitted), occasionally with black dots in center of white areas; in last stages, annual rings separated, finally spongy; fine felty masses (mycelium) under bark scales; delignifying rot; conical, uniform, filling heartwood and part or all of sapwood.

³ Uniform heart-rot (principally of trees with little or no resin); in early stages, a light-yellow stain; typical stage, yellow or honey color, brownish streaks; yellowish to light tan or white felty masses running across the grain and breaking up in last stages and separating annual rings, finally becoming hollow rotted; carbonizing rot; conical in heartwood.

It is readily seen that Table I will aid greatly in determining the rot in the tree by means of external characters, and after the class of defect and the cause have been determined by its use it will be comparatively easy to select the proper rot column in the table of rot percentages for any one tree species. In this manner the two tables can be used conjunctively in securing a more accurate rot percentage for the stand.¹ Until it is possible to obtain accurate data from a large number of trees of all the species composing the prevalent

forest types of this region, no table of rot percentages will be presented.

Since the type lines are sketched on the topographic map on the basis of age class, it will be found advantageous to study and record the rot data upon such a basis. This will make it easier to produce pathological maps of the area by using white prints from the type-sheet tracings of the timber survey maps.

In a unit crew consisting of two men (an estimator and a topographer),

the estimator can be trained to determine the cause of the disease and the amount and therefore the rot percentage, recording such data accurately for the strip which is being surveyed. Since the estimate sheets have blank spaces for the recording of all disease and other injuries suffered by the stand, as well as for the estimated loss in cull due to each, the only change that a more intensive disease survey will incur will be the additional work done by the topographer. He will be required to indicate upon his map the boundaries



FIG. 18.—Typical rot of the scaly *Pholiota* in grand fir. Note the horizontal streaks formed by the yellowish felty mycelium.

¹ Weir, J. R. Difficult problem of the control of fungus diseases in the forest. *In* Timberman, v. 14, no. 9, p. 27–29, illus. 1913.

Weir, J. R. Some problems in conservation with reference to forest hygiene. *In* Timberman, v. 14, no. 11, p. 28–31, illus. 1913.

Meinecke, E. P. Forest tree diseases common in California and Nevada. Washington, D. C. 1914. These publications may be found useful in the determination of various kinds of defects.

of the various infections and to show therein the estimated cull due to each. This information can easily be secured by coobservation with the estimator, who can supply the actual figures for the rot percentages and aid in determining the boundary lines of infection. This will produce sufficient reliable data upon which to base valuable pathological maps, which can be compiled either with colored areas to indicate the diseases and inclosed figures indicating the rot percentages or can be drawn in black and white, using lines dif-



FIG. 19.—*Razoumofskyia campylopoda*, mistletoe, on yellow pine.

fering from type lines to indicate the boundaries of the infected areas and placing the rot percentages in figures within this area.

PATHOLOGICAL MAPS.

Maps indicating the distribution of diseases in forest areas have not been used to any great extent. In German literature, articles are to be found dealing with plant diseases which have such maps illustrating the distribution of the disease. Very few contain maps dealing with the distribution of forest-tree diseases and none at all dealing strictly with the distribution of fungous infection in forests.

In this country considerable use has been made of disease-distribution maps by the various workers along the line of plant and forest

pathology. This is noticeable in the work done in the study of the chestnut-blight fungus¹ and in the study of two of our important forest-tree rusts.² These are all maps of the plain black-and-white type, showing by means of symbols the localities where infection was reported and thus indicating the distribution of the disease. The earliest colored maps used in forest-disease investigations are found in German literature and deal mainly with the distribution of zones of timber damaged by smelter fumes.

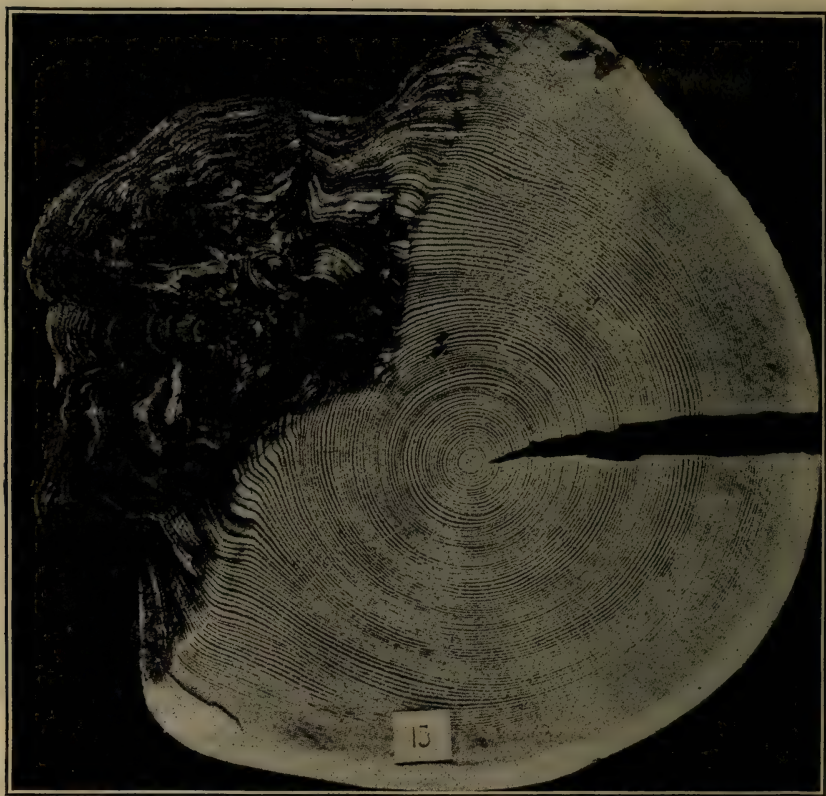


FIG. 20.—Mistletoe burl affecting one side of larch log. Size of burl, 3½ feet long by 13 inches in diameter. The cull equaled 25 feet board measure.

Colored maps giving the distribution of smelter-smoke damage were published in a book on smoke damage to vegetation by

¹ Rankin, W. H. Field studies on the *Endothia* canker of chestnut in New York State. *Phytopathology*, v. 4, no. 4, p. 237. 1914.

² Spaulding, Perley. The blister rust of white pine. U. S. Dept. Agr., Bur. Plant Indus. Bul. 206, 88 p., 2 pl. (1 colored). 1911. Bibliography, p. 61-78. Map showing distribution of blister rust in Europe, p. 14.

Hedgcock, G. G., and Long, W. H. A disease of pines caused by *Cronartium pyriforme*. U. S. Dept. Agr. Bul. 247; 20 p. 1915. Literature cited, p. 20. Map showing distribution of *Cronartium pyriforme*, p. 8.

Schroeder and Reuss in 1883.¹ Other works by Schroeder and Schertel in 1884² and Borggreve in 1893³ also give maps in connection with studies of smoke, the latter maps being uncolored. No references were found which contained colored maps of the distribution of forest-tree diseases.

In the making of timber-survey maps, type boundaries are indicated by continuous dotted lines inclosing within the areas so formed the figures indicating type mixture, density, and age class, the age class also being separated by dotted lines. Very often these areas are colored by the use of wash inks or crayons, so as to make a greater distinction between them. A number of standard colors are used and are applied upon white prints, which are found to give the best results. A similar method is proposed for use in making pathological maps, the only variation being the addition to the type-sheet maps of boundary lines indicating the infected areas and a special set of colors indicating various diseases. In the pathological maps only those colors denoting the various infections should be used, leaving the type areas uncolored.

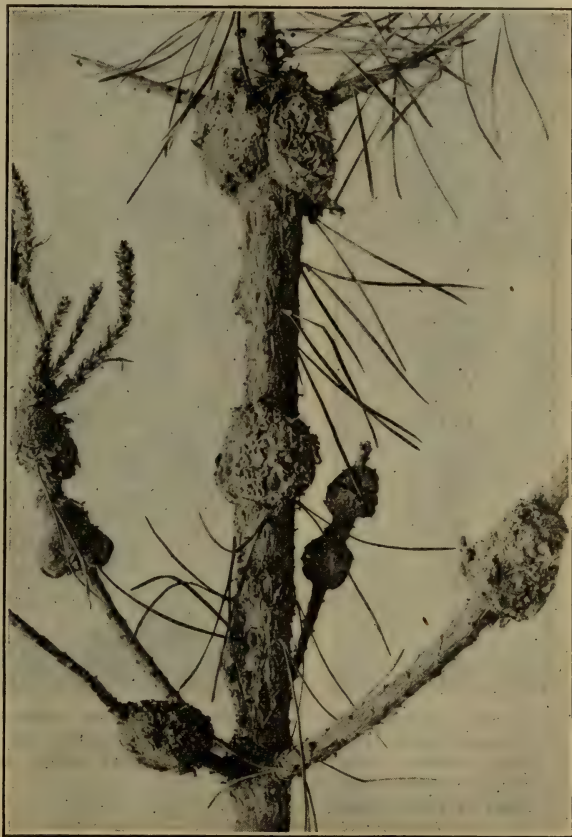


FIG. 21.—*Cronartium côleosporioides*, pine rust, gall form, on young lodgepole pine. The two galls on the main stem are fruiting. Note the small white cups scattered over the surface of these two galls.

¹ Schroeder, Julius von, and Reuss, Carl. *Die Beschädigung der Vegetation durch Rauch und die Oberharzer Hüttenrauchschäden*. 333 p., 2 maps (colored). Berlin, 1883.

² Schroeder, Julius von, and Schertel, A. *Die Rauchschäden in den Wäldern der umgebender physikalischen Hüttenwerke bei Freiberg*. Separat-Abdruck Jahrb. Berg. w. Hüttenw. Königr. Sachsen, 1884, p. 93-120, map (colored). 1884.

³ Borggreve, B. *Rauchbeschädigung in dem von Tiele Winkler'schen Forstreviere Myslowitz-Kattowitz*. 236 p., 2 maps. 1893.

The maps will be found valuable not only as an interpretation of the data taken in intensive disease surveys in connection with timber surveys but in the appraisal, marking, and general administration of the sale area. With regard to appraisal the map will indicate the location of seriously infected areas and also the rot percentages. With respect to marking, the map will show the exact area of the



FIG. 22.—*Cronartium coleosporioides*, pine rust, blister form, on 2-year-old seedlings of yellow pine.



FIG. 23.—*Cronartium coleosporioides*, pine rust, blister form, an old infection, on the main trunk of lodgepole pine, known locally as "hip canker" or "cat-face."

most seriously infected trees and aid in the exclusion of infected trees for seed trees. From the standpoint of general administration, the maps will show the location of sites and age classes upon which heavier marking must be employed in order to conform with the most effective sanitation clauses.

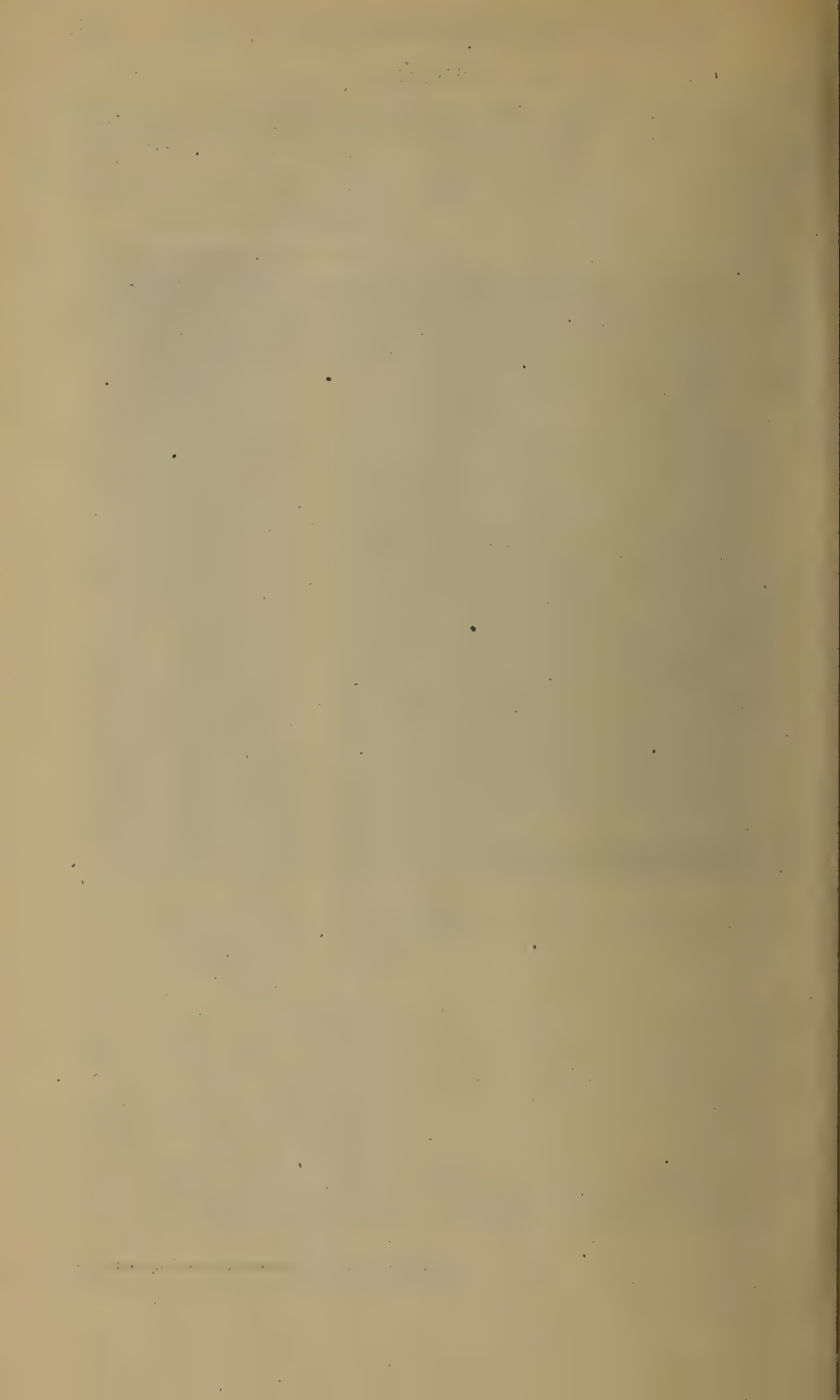
With regard to reforestation by artificial or natural means, these maps will show the proximity of infected stands and whether or not the site has been or apparently is favorable to excessive disease.

SUMMARY.

Forest disease surveys when carried out in conjunction with timber-survey projects will furnish data of economic value in conducting future sales of the areas in question.

Pathological maps indicating the principal infection areas can be compiled from the data secured by these forest disease surveys.

These maps will be found of practical value in the appraisal, marking, and general administration of the sale area. They will prove of practical use in both artificial and natural reforestation and will also prove useful in indicating the general distribution of forest-tree diseases in our National Forests.



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PROFESSIONAL PAPER

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A STUDY OF HEART-ROT IN WESTERN HEMLOCK.

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INTRODUCTION.

From the fact that the experience and methods of the European countries have been worked out and are at present practiced under an entirely different set of conditions, forestry in America is confronted with the necessity of formulating its own fundamentals as regards forest organization, working plan, and general silvicultural procedure in the virgin forests of the Northwest. Since a large number of the basic principles of an ideal forest organization depend upon a proper understanding and appreciation of the progress of decay in the forest and the general deterioration of the stand and of individual trees, the problem is largely one of a pathological nature. The need of reliable figures from which an adequate conception of the loss to the forest through the death and disease of individual trees or stands and through various other causes instrumental in reducing the maximum annual increment is self-evident when any attempt is made to establish a rotation or cutting age for any one species. It is necessary also to concentrate the collection of these data upon a single tree species or upon a single type in order to secure

figures which can be applied to the practical operations of forestry. Meinecke,¹ in a recent paper on this subject, has clearly expressed the need of concentrated work upon single tree species, with a special aim to secure accurate data adaptable to practical use. In order to make a beginning in supplying the fundamental knowledge for a solution of some of the more vital problems bearing on the regulation of the forest with regard to the peculiarities and activities of the more economic fungi, a series of detailed studies has been instituted, beginning with the western hemlock (*Tsuga heterophylla*). In the present study, an attempt has been made to secure for two principal types of the typical stand all available data bearing on the relationship of decay to the many factors concerned in its inception, development, and spread, and to determine, if possible, which of the factors concerned in the life history of western hemlock has the greatest influence in the development or retardation of decay.

PRESENT STATUS OF WESTERN HEMLOCK IN THE TRADES.

The regulation of hemlock in the northwestern forests is probably one of the most difficult silvicultural problems with which foresters have to deal. Not only has this species for many years in some parts of the West been considered little more than a "weed" in the forest, to be removed in as expedient and thorough a manner as possible, but a widespread prejudice on the part of the lumber trade has kept the products of western hemlock much in the background.

The common occurrence of heart-rot, the susceptibility to fire and frost, etc., have also led to a much advanced theory of a general decadence of this really valuable species. Western hemlock can not be considered in any sense a decadent tree, as is evidenced by its splendid height and diameter growth in localities where it reaches its best development. There are approximately 90,000,000,000 feet board measure of western hemlock in the United States and Alaska, and most of this is found in Washington and Oregon.² Only recently have the millmen placed hemlock upon the market under its rightful name. In 1908, 90,000,000 feet of western hemlock were reported cut, and this increased to 248,000,000 feet in 1910.² The rapid increase in cut tends to show that the true value of western hemlock is hereafter to be recognized and that the prejudice against its name is gradually disappearing.

Several mill owners with whom the subject of the soundness and durability of hemlock lumber has been discussed state that too frequently the lumber decays rapidly after being sawed. This is not

¹ Meinecke, E. P. Forest pathology in forest regulation. U. S. Dept. Agr. Bul. 275, 62 p. 1916.

² Hanzlik, E. J., and Oakleaf, H. B. Western hemlock; its forest characteristics, properties, and uses. In Timberman, v. 15, no. 12, p. 25. 1914.

due to a poor physical quality of the wood, but usually arises from the fact that great difficulty is experienced in determining the actual extent of the advance decay from the more evident heart-rot when the trees are bucked and scaled in the woods. Some of the logs go to the mills to all appearances sound, but in reality with a part of the log in the incipient stages of decay. Consequently, when the log is sawed into boards they check or completely fall into a dry crumbly decay when exposed to drying conditions for any considerable length of time. Such conditions cause a discrimination against western hemlock by those who have witnessed this deterioration after sawing. A better understanding of the real causes underlying this result and a true conception of the usefulness of hemlock wood will aid greatly in removing such objections as the trades now hold against lumber sawed from this species of tree.

ECHINODONTIUM TINCTORIUM.

THE FUNGUS AND ITS HOSTS.

With few exceptions, as will be shown, *Echinodontium tinctorium* E. and E. (figs. 1 and 2) is the cause of practically all the heart-rot so widely prevalent in hemlock throughout the Northwest. Being the only hydneaceous fungus of its kind and the only member of its genus, something of its history should be given. The fungus was first described as *Fomes tinctorium* by J. B. Ellis from the original specimens collected in Alaska by J. G. Swan. The teeth were broken from these specimens, and Ellis mistook the pits or scars for pores and called it a *Fomes*.¹ The fungus was next collected at Jansville, Idaho, by C. V. Piper, who sent it to Lloyd. Lloyd published it as *Hydnum tinctorium*.² In a letter to the senior writer, Lloyd states that Ellis suggested that the fungus might well be the type of a new genus and should be called *Echinodontium tinctorium*. Lloyd used this name in his article and it was the first time the name was employed. In 1900, Hennings, of the University of Berlin, received some small specimens from Japan. Ignorant of the work of Ellis and Lloyd, he published the fungus as representing a new genus, calling it *Hydnofomes tsugicola*.³ The name *Echinodontium* first published by Lloyd has become so thoroughly established in forestry circles that any attempt to depose priority and use any other names, which in some respects are far more applicable, for instance, *Hydnofomes*, would lead to some confusion in the ranks of practical foresters; hence the name given by Ellis and Lloyd will be used.

¹ Ellis, J. B. New fungi, mostly Uredineæ and Ustilagineæ from various localities, and a new *Fomes* from Alaska. In *Bul. Torrey Bot. Club*, v. 22, no. 8, p. 362. 1895.

² Lloyd, C. G. Mycological notes, no. 1, p. 2-3. 1898.

³ Hennings, Paul. *Fungi japonici*. In *Bot. Jahrb. [Engler]*, Bd. 28, Heft 2, p. 268. 1900.

The chief gross character by which the fruiting organ of the fungus may readily be recognized is a hymenium consisting of numerous firm, thick, sharp-pointed teeth of a light-brown color (figs. 1 and 2). The upper surface is almost black in old specimens (figs. 3 and 4), usually of a lighter color when young, and concentrically zoned, each zone representing a year's growth. In a growing condition the outer zone is white or brown, context solid, and of a Mars-orange to orange-rufous color.¹ The minute characters of the fruiting organ are: Spores hyaline, broadly ellipsoid, 4 by 6 μ , teeth covered with



FIG. 1.—Sporophore of *Echinodontium tinctorium* on hemlock. Bottom view, showing fresh hymenium or spore-producing surface.

short colorless setæ or microscopic spines. The hymenium of the young growing fungus is by no means toothed in the beginning but is typically dædaloid, a character often misleading to the uninitiated when the interior has not been examined.

On account of its tinctorial property, the powdered fungus mixed with tar or oil is used by the Indians as a war paint. The fungus is likewise employed by the Indians of Alaska for medicinal purposes and as a dye. For the latter reason it has received the common name of Indian-paint fungus. Since an oily alkaloid has been detected by the analysis of the fungus, there is a possibility of its

¹ Ridgway, Robert. Color Standards and Color Nomenclature, pl. 2. Washington, D. C., 1912.

possessing therapeutic properties of some value. Tannin has been found in considerable quantities in the fungus.

From specimens preserved in the Laboratory of Forest Pathology at Missoula, Mont., the host range of *Echinodontium tinctorium* is as follows: *Tsuga heterophylla*, *T. mertensiana*, *Abies grandis*, *A. concolor*, *A. lasiocarpa*, *A. nobilis*, *A. magnifica*, and *A. amabilis*. The fungus has not been reported on *A. venusta*. Its occurrence on *A. arizonica* is reported by Hedgcock.¹ In the very rarest of cases *E. tinctorium* occurs on *Picea engelmanni* and *Pseudotsuga taxifolia*. The fungus rarely occurs on any but its common hosts and is only of economic importance in the consideration of problems relating to the genera *Abies* and *Tsuga*. The specimens which reached Berlin from Japan grew on *Tsuga diversifolia*.

GEOGRAPHIC DISTRIBUTION.

In view of the fact that many of the more serious wood-destroying fungi are distributed over the world, it is interesting to note that the geographic range of *Echinodontium tinctorium* is limited. Except the specimens from Japan, it has not been found outside of western North America. To judge by specimens on hand in the Laboratory of the Office of Investigations in Forest Pathology of the Bureau of Plant Industry and as reported by others, the range of this fungus in North America extends from Alaska to northern Mexico and as far eastward as the limits of the range of grand fir and hemlock on the western slopes of the Continental Divide in Canada and Montana.



FIG. 2.—*Echinodontium tinctorium* growing out of a blaze, which was the source of infection. Note the spines on the fungus.

¹ Hedgcock, G. G. Notes on some diseases of trees in our National Forests. In *Phytopathology*, v. 2, no. 2, p.78. 1912.

The fungus is most abundant and of greatest consequence in western Montana, Idaho, Oregon, Washington, and British Columbia.

THE DISEASE CAUSED BY *ECHINODONTIUM TINCTORIUM*.

OUTWARD SIGNS OF THE DISEASE.

To be able to recognize or discriminate between the more dangerous and less harmful diseases should be a part of the everyday knowledge of the forest officer in charge of the marking. The following statements will be of some value in this respect.

The decay-producing fungus proper is the mycelium in the wood, not the "conk" (fig. 5) without. The appearance of a fruiting body



FIG. 3.—Sporophore of *Echinodontium tinctorium*, showing upper surface.

is in most cases an index of the intensive development of the fungus, at least within a certain volume of the tree infected. It means that a good part of the food materials of the heartwood at that point are exhausted. A single average-sized sporophore situated on the first 16 feet of the trunk for all practical purposes may be taken to indicate an unmerchantable condition of the heartwood of all points below and into the next 16-foot log above the first. A sporophore situated well up on the trunk may be taken to indicate undesirable material throughout the main part of the tree. Little need be said concerning the presence of more than one sporophore. It will be observed that the largest usually has smaller ones above and below it.

This generally indicates that the largest sporophore marks the area of greatest decay and that the decay has traveled both ways. In any case, trees bearing more than one sporophore situated some distance from each other are not merchantable and should be cut down and burned or fire-girdled.

The presence of sporophores on the tree is an indication of a fairly advanced stage of decay throughout a good portion of the tree. On the other hand, the absence of sporophores does not always indicate soundness. A few cases may occur where the tree is so old in decay that the sporophores have died and fallen away. The discoloration of the bark at the point of attachment or the hole left by the rotting

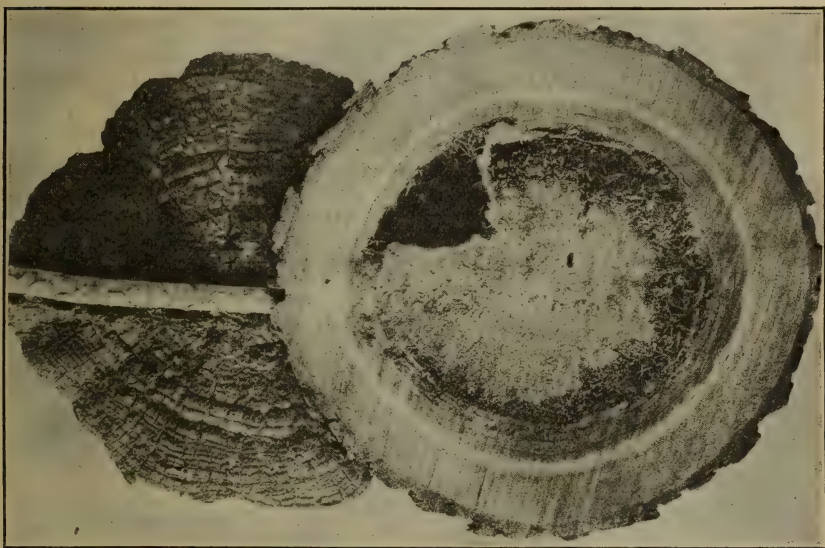


FIG. 4.—An old sporophore of *Echinodontium tinctorium* on hemlock. Top view, showing the zonation and the relation to intensive decay.

branch may readily be noted. The old sporophores, which have a remarkable resistance to decay, may be observed on the ground at the base of the tree. Pounding on the tree is a fairly accurate method of determining soundness, down to a particular stage of rot. In doubtful cases, remarkably accurate results may be obtained by pressing the ear firmly against the tree while pounding. Previous to this, the bark should be removed over a small area in order to secure an uncushioned sounding point.

Probably the most practical method for the average marking officer, in the absence of visible defects, is the presence of red color a half inch or so within the dead branch stubs. This reddish coloration of the rot *E. tinctorium* is an index of an advanced stage, and its appearance so far out on the dead branch as to be detected by merely breaking

off the branch is a sure sign of the typical rot within. The red color may not show at the base of every branch, in which case several may be examined. If the red color does not show after the knot has been opened with the corner of an ax, the branch may still show a yellowish, dry-rot or the usual flinty consistency of a naturally pruned branch has given way to a loosened condition of its annual rings. This may be taken to indicate an initial stage of the rot only at this point, however, for the heartwood of the tree may be entirely decayed, due to the fungus having entered at another point. Knocking off



FIG. 5.—Sale area after logging (private logging operations), showing defective hemlocks left standing, a waste of valuable material and a menace to the surrounding forest. Note the “conks” on the trunks.

a few dead branches with an ax does not require much time and is a very good method to use in such a case.

In general, individual trees growing under suppressed conditions or a type developing in a close stand can be expected to disclose a large amount of decay, especially when growing on moist river-bottom sites. The slope type of stand must be judged more carefully, and it is often the case that in vigorous stands an infected tree will yield the first two logs sound while the upper portion of the trunk will be in the last stages of decay. Under such conditions sounding by blows will not be found practicable, but the presence high on the trunk of many branch stubs, dead branches, and sporophores will

always indicate the true condition. Moist sites of various slopes and exposures are generally found to produce a greater development of decay, and invariably the older trees in such stands are badly infected. This is indicated by the data secured from lumbermen given in the pages that follow. The early formation of branch stubs through the premature dying of the lower crown due to overshadowing can always be depended upon as an indication of existing decay, and it will usually be found that the center of infection is located in that portion of the trunk bearing the largest number of dead branches or branch stubs. The presence of many branch stubs, the presence of branch stubs showing unmistakable rot colorations, the appearance and number of sporophores, many injuries (including frost cracks), old age, and unmistakable signs of reduced vigor are all very reliable indications upon which a marking officer may learn to base his judgment for the determination of decay in western hemlock.

GENERAL CHARACTERISTICS OF THE ROT.

The spores of *Echinodontium tinctorium* upon germination penetrate the

host mainly through the dead broken branches or branch stubs (figs. 6 and 7). This has been confirmed by the data taken in the study of the relation of injuries to decay. A few infections are traceable to fire and logging scars, frost cracks, or other injuries. In a few instances, on areas other than those upon which data were secured, it has been found that the burls on hemlock caused by *Razoumofskyia tsugensis* were points of infection.

The hyphæ on germinating follow the central nonresinous heartwood zone of the branch stubs and continue inward to the main heartwood of the tree (fig. 8), spreading more or less uniformly up and down the trunk from the point of infection. The decay is char-



FIG. 6.—Cross section of a young hemlock, showing heart-rot at a whorl of branch stubs. In this case there are five dead branch stubs, all of which were possible agencies in conveying the disease into the heartwood.

acterized in hemlock and grand fir by its uniformity in occupying the heartwood (figs. 4 and 8). In alpine fir the rot in cross section takes on a somewhat stellar development, due principally to the concentration of the hyphæ along certain of the medullary rays.

In badly decayed living trees it is invariably the case that the rot not only occupies the entire heartwood of the trunk but the heartwood of the branches as well (fig. 9), extending in some of the larger ones a distance of several feet,¹ causing the formation of sporophores at some distance from the trunk.

The advance rot of *Echinodontium tinctorium* is very difficult of detection and unless accompanied by small brownish discolorations

or by reddish or brownish streaks can not be detected without a very close examination. In the early stages of the decay the wood assumes a faint yellowish, spongy texture. Sometimes this stage is intensified by the presence of small, hardly discernible brownish areas, which later develop into the typical rot. The extension of the advance rot beyond the typical rot varies greatly according to the con-

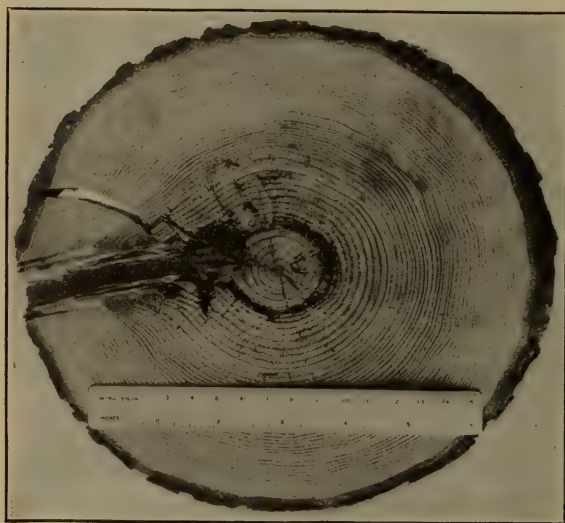


FIG. 7.—Section of hemlock, showing a branch stub as a means of first infection of heart-rot. The decay has commenced spreading into the heartwood from the end of the branch tissue.

ditions. Some accurate data are at hand to determine the average height of the advance rot beyond the typical rot. Such data will be found very useful to scalers in determining the amount of cull to deduct from the gross scale in order to cut out all the advance rot which might later develop into the crumbly decay complained of by dealers in hemlock lumber. Meinecke² states that in the white fir (*Abies concolor*) of this region the advance rot produced by *E. tinctorium* extends about 2 to 6 feet beyond the typical rot. From the data collected on more than 200 hemlocks of all ages and sizes an extension of 1 to 5 feet has been found to be general. A single figure

¹ Weir, J. R. Destructive effects of *Trametes pini* and *Echinodontium tinctorum*. In *Phytopathology*, v. 3, no. 2, p. 142. 1913.

² Meinecke, E. P. Forest-tree diseases common in California and Nevada, p. 52. 1914. Published by U. S. Department of Agriculture, Forest Service.

can not be used to express this relation, since it varies with all the factors influencing the progress of the decay. As a rule, it would be safe to add to the linear estimate of the cull $1\frac{1}{2}$ feet beyond the last recognizable punky area or area showing the slightest yellowish discoloration. The typical rot (figs. 4, 8, and 9) is readily recognizable and has a characteristic reddish brown to brownish yellow color, often spotted with areas of a more vivid rust color and occasionally showing streaks or lines of a dark red to reddish brown hue. Its texture is very pronounced and this, combined with its color, forms the basis for the scaler's common name for the defect "stringy brown-rot." In the last stages of decay the heartwood is entirely disorganized, giving place to large cavities in the butt logs and sometimes in the logs above. The stringy nature of the rot can be readily seen in this stage and also in the ends of logs badly but not hollow

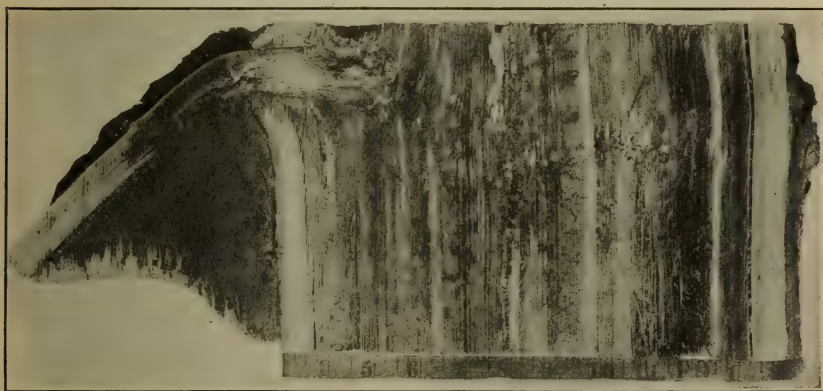


FIG. 8.—Longitudinal section of an old sporophore of *Echinodontium tinctorium* on hemlock, showing its relation to branch stubs.

rotted, especially in the grass-stubble effect (figs. 4 and 10) produced by the sawing. The brick-red color of the sporophores is often found distributed through the typical rot and in the branch stubs in the final stages of decay.

AREAS STUDIED AND FIELD METHODS USED.

The areas selected for study lie in the drainage basin of the Priest River in Idaho. Throughout this region western hemlock is rather evenly distributed, extending downward from the subalpine zone into the upper limits of the yellow-pine zone. The species attains its best development on damp north slopes and is found greatly suppressed when growing as an understory in the dense bottom stands.

One of the factors promoting the development of forest-tree fungi of the region is the high annual precipitation. The dry periods of

the year are comparatively short, so that the sporophores of perennial fungi may never at any time be entirely dried out. During the late fall, extending into December and coincident with the formation of new fruiting surfaces of the Indian-paint fungus, rain falls almost constantly. The average annual precipitation is between 20 and 30 inches, increasing rapidly with elevation, reaching a maximum of more than 40 inches in the higher slopes.

In the spring of 1915 investigations were begun on the river-bottom and slope sites of the Priest River valley in Idaho. The general altitude of the region is about 2,450 to 2,500 feet. The meanderings of the Priest River in former times created a number of

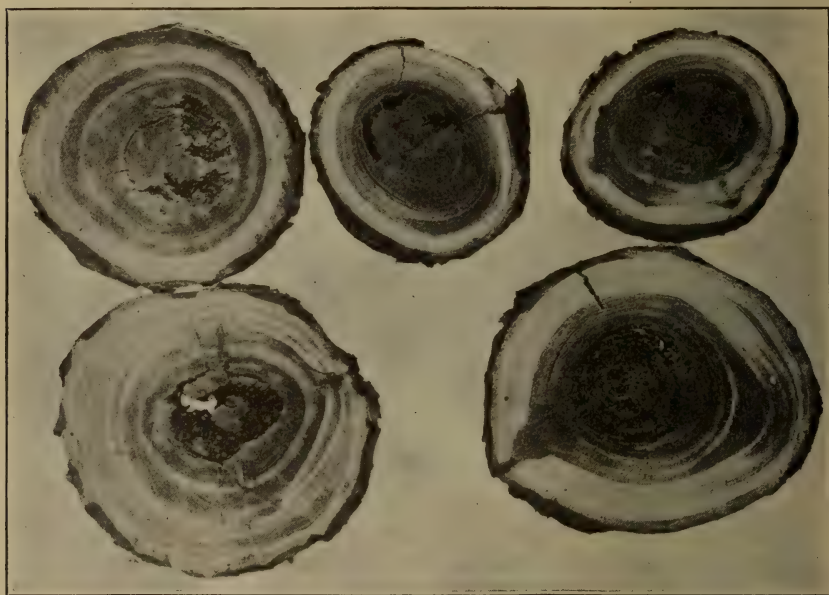


FIG. 9.—Cross sections of a hemlock branch in which heart-rot extended 10 feet out from the trunk, showing how the larger branches may be affected.

swamps and bayous, which are filled with water during the greater part of the year. The interlying areas are poorly drained.

The whole region is one of dense forests, composed of western white pine (*Pinus monticola*), western red cedar (*Thuja plicata*), western larch (*Larix occidentalis*), Engelmann spruce (*Picea engelmanni*), Douglas fir (*Pseudotsuga taxifolia*), western hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*), western yew (*Taxus brevifolia*), western birch (*Betula occidentalis*), and cottonwood (*Populus trichocarpa*).

The soil is a moist sandy loam, with much alluvial material and not well drained on the river-bottom sites. There is a great depth of humus, litter, and needles. On the above-described site, ten

separate plats were laid out, comprising 5.7 acres. The river-bottom and slope types were first selected for investigation, for the reason that at these elevations and under the existing conditions grand fir and hemlock are heavily diseased. The plats represented a variety of age classes, mixtures, and successions.

The investigations on grand fir and hemlock were carried out simultaneously, but the data on the former are reserved for a future report. The influences of site and elevation on the distribution and amount of decay were considered, and the data were consequently divided according to the two sites indicated. In order to get the percentage of rot of hemlock and grand fir, a clean cut of these species



FIG. 10.—Section through a trunk of hemlock, with an old sporophore attached. The stringy nature of the heart-rot and the grass-stubble effect due to sawing are both characteristic.

was made. The trees were bucked in such lengths (16 feet and shorter) as to determine the transverse and longitudinal extent of the decay; also the point at which the decay was greatest. That section of the trunk containing the upper extension of the decay was fully dissected, in order to determine the exact upper limit. The diameter of the rot at each log end was measured and recorded. The rot in each tree was measured in detail. A full analysis of the stump was also made. A uniform stump height of 18 inches was maintained throughout. The age of the tree was determined at this point, and four years added to the age at the stump, giving the entire age.¹ Before the trees were felled, full notes on the external

¹ This average age at stump was secured by taking data on a number of seedling hemlocks in the same stand and determining the age corresponding to the stump height of the felled trees.

appearance relative to environment, etc., were recorded. Each tree was designated by a number. Altogether, 201 trees of western hemlock were cut on the ten areas, and about an equal number of grand fir. The hemlocks considered in this study are numbered from 1 to 201. No selection of trees was practiced, but all trees on the areas laid out were cut.

Aside from a few cases of secondary decay, the cause of which could not be definitely determined from a chemical and anatomical study of the rot alone, the occurrence on hemlock of the more common fungi of the associated species was practically nil. In a few cases the rot of *Trametes pini* and *Polyporus schweinitzii* was found in hemlock, but since the merchantable parts of the same trees were wholly decayed by *Echinodontium tinctorium*, all decay of the species on the areas is attributed to the latter. This is equivalent to saying that practically 100 per cent of all cases of decay in living hemlock were due to *E. tinctorium*. This is by no means an unusual condition for the region. In fact, the finding of any other fungus working as a first agent of decay in hemlock is a rarity.

METHODS USED IN PRESENTING DATA.

The methods used in preparing the data for presentation and comparison are the result of an attempt at standardizing such factors as, in ordinary field observations, are usually determined by an ocular method not involving exact measurements. Any attempt at standardization of such factors as are included under "Seriousness of injury," "Degree of vigor," or "Crown rating" is bound to meet with difficulties. So long as the same standard is used consistently throughout the work, a slight amount of arbitrary standardization will not in the least reduce the value of the results.

The total volume of the tree, less the stump, inside of the bark was first secured in cubic feet by means of the paraboloid formula,¹ $V = (BH \div 2)$, and the table of basal areas.² The diameter (inside of the bark) at the stump was used to secure the above figure. The total volume of rot in the tree, less the stump, was secured in cubic feet by a similar method. As an experiment to determine the shape of the rot column, the outlines of the rot column of several infected hemlocks were plotted on coordinate paper. It was found that these rot outlines conformed closely to the general outlines of the trees. It was also found that the formula used to secure the volume of rot more nearly included all the rot found within the trunk than did the Smalian method. The dissection of the trees and the plotting of a few of them on coordinate paper showed that the formula as

¹ Graves, H. S. Forest Mensuration, ed. 1, p. 88. New York, London, 1906.

² Graves, H. S. Op. cit., p. 430.

here used allowed for such rot as was to be found outside of a straight line drawn from points on the rot sections appearing at both ends of the logs and such rot as was found extending outward from the heart-wood along the branch whorls. The advance rot is included in the total rot in every case. The rot percentage was secured from the two given volumes.

The basis for classifying the seriousness of injury is given as follows:

0 = No injuries.

x = 1 to 4 branch stubs, no frost cracks, and very few miscellaneous injuries (less than 2).

xx = 5 to 9 branch stubs, one frost crack, and a superficial blaze, logging scar, or other slight injury.

xxx = 10 to 15 branch stubs, not more than 2 frost cracks, deep blazes, logging scars or fire scars, and slight lightning injury.

xxxx = 15 or more branch stubs, more than 2 frost cracks, and heavy injuries (injured and broken top, severe lightning, and other injuries).

The grouping of trees according to the crown class has, in general forestry practice, been almost entirely done by ocular estimate. In the present study the four gradations of the crown class were taken from Forest Service Bulletin 61¹ and were used with the crown size in composing the standard for crown rating. The actual size of the crown and the crown class are used to determine this rating. The crown sizes in square feet (length by width of crown) for each age class are grouped together, the largest and smallest sizes compose the extremes of the large and the very small crown divisions, respectively, the remainder ranging in order of size between these two. The group is then divided into four equal classes: Large, average, small, and very small. The individual trees are then given their respective crown rating according to the following outline:

(1) Crown size, large. (Crown class 1.)

(2) Crown size, average. (Crown class 2.)

(3) Crown size, small or one sided. (Crown class 3.)

(4) Crown size, very small. (Crown class 4.)

The vigor of a tree is indicated by the size and condition of its crown and by the favorableness or unfavorableness of the position it occupies, as well as by the narrowness of the sap zone and the fineness of its annual rings. The injuries which the tree receives during the course of its development also play an important part in influencing its vigor. The rating for vigor has therefore been based upon the following three factors, in the order of their importance: (1) Width of average ring in sap, (2) crown rating, and (3) the degree of injury. This rating for vigor at least comes nearer registering the true condition than a mere ocular estimate. The fixing of the standard or average width (as in *oo* where the width is 0.12 to 0.19 inches) was

¹ Terms used in forestry and logging. U. S. Dept. Agr., Bur. Forestry Bul. 61, 53 p. 1905.

secured from a careful checking of all the data and from the table by Hanzlik and Oakleaf ¹ giving the average annual diameter growth for western hemlock as obtained under average conditions in western Washington.

Rating of Vigor.

- o=Thrifty.—Width of average ring in sap 0.20 inches and up; 1 in crown rating; classed as 0 or x under degree of injury.
- oo=Fair.—Width of average ring in sap 0.12 to 0.19 inches; 2 in crown rating; classed as x or xx under degree of injury.
- ooo=Poor.—Width of average ring in sap 0.04 to 0.11 inches; 3 in crown rating; classed as xx or xxx under degree of injury.
- oooo=Low.—Width of average ring in sap 0.03 inches and less; 4 in crown rating; classed as xxx or xxxx under degree of injury.

Other methods specially adapted to develop certain data will be found explained under the headings which follow.

The size of the average ring in the sap is the most important factor in the vigor determinations. The injury ratings (as *x* or *xx*) in the *oo* vigor class are intended to give a certain leeway in so far as the injuries found on the trees are concerned. Many trees have an *x* rating for injury, yet the vigor as indicated by crown size and by width of average ring in sap indicates a thrifty tree. A similar leeway is given the other vigor classes.

INFECTION AGE.

In studying the life history of a particular type, such as the river-bottom type of western hemlock, it becomes evident in the course of the work that certain age classes within that type represent a definite stage in the development of decay. This has been brought out by Meinecke ² in his work on white fir (*Abies concolor*). The factors governing the entrance and development of a fungus in its host tend to determine a certain average age which indicates the age of first infection, an age at which the stand is most liable to first infection by the fungus and below which the infection rarely occurs.

Judging from Meinecke's ³ discussion of the age of infection, he defines it as the age at which "infection rarely leads to more than negligible decay unless the tree is handicapped by quite unusually severe conditions." An attempt has here been made more accurately to define this average age. The youngest trees only were used and of these only those which were infected. This age is briefly outlined as the average age of the youngest trees open to first infection by the fungus.

¹ Hanzlik, E. J., and Oakleaf, H. B. Western hemlock; its forest characteristics, properties, and uses. *In* Timberman, v. 15, no. 12, 1914, p. 25-33, tab. 3.

² Meinecke, E. P. Forest pathology in forest regulation. U. S. Dept. Agr. Bul. 275, p. 47-48. 1916.

³ Meinecke, E. P. Op. cit., p. 48.

Table I represents all the trees of the 41 to 62 age class, inclusive, taken from plats classed in the river-bottom and southwestern-slope types. The 15 and 9 youngest trees of each site (river bottom and southwestern slope), respectively, were used to secure an average age representing the infection age. This age for each tree was secured by means of the formula, $A_1 = A - (V \div V_1)$, where A_1 equals age of first infection, A equals age of tree, V equals volume of rot of the tree, and V_1 equals the average annual increase in rot volume for the age class in which the tree is included. This last figure is obtained from Table II. It was attempted to use the first 15 trees of the southwestern-slope type. This gave an infection age of 70 years but included trees as old as 99 years, while the oldest tree of the river-bottom type was only 62 years. In using 9 trees, the oldest tree of the slope site is 75 years, giving a more equal comparison.

TABLE I.—*Data relating to the infection age of heart-rot in western hemlock on plats of the river-bottom and southwestern-slope types.*

Age.	Tree No.	Volume of rot.	Approximate value for $V \div V_1$.	Probable age of infection. ¹	Number of infected trees(basis).
River-bottom type: ²		<i>Cubic feet.</i>	<i>Years.</i>	<i>Years.</i>	
46 years.....	82	0.07	2	44	13
48 years.....	83	.03	1	47	
54 years.....	84	.06	2	52	
54 years.....	85	.68	19	35	
55 years.....	86	.32	9	46	
55 years.....	87	0	0	0	
56 years.....	88	.36	10	46	
57 years.....	89	.27	8	49	
57 years.....	90	.19	5	52	
58 years.....	91	.44	13	45	
60 years.....	92	0	0	0	
61 years.....	93	.59	17	44	
62 years.....	94	1.11	32	30	
62 years.....	95	1.13	32	30	
62 years.....	96	.12	3	59	
Average.....				44.5	
Slope type: ³					
54 years.....	1	0	0	0	4
57 years.....	2	.07	4	53	
60 years.....	3	0	0	0	
62 years.....	4	0	0	0	
67 years.....	5	0	0	0	
70 years.....	6	.17	9	61	
72 years.....	7	.51	26	46	
75 years.....	8	.11	6	69	
75 years.....	9	0	0	0	
Average.....				57.3	

¹ Formula: $A_1 = A - (V \div V_1)$. $V_1 = 0.035$.

² Site description.—River-bottom flat, very moist; soil not well drained; stand very dense. Almost all individuals of the tolerant species, such as western hemlock and grand fir, were overtopped or suppressed.

³ Site description.—Southwestern slope, partly flat; old-age class of a white-pine type in which the hemlock has become a climax species; soil fairly moist and well drained; stand not overcrowded.

Table I shows that the average infection age for the river-bottom type is 44.5 years and for the southwestern-slope type 57.3 years. It thus appears from a comparison of the results shown in this table

that the average infection age for the slope type is higher than that for the river-bottom type. This is undoubtedly due to the fact that the environmental factors in the river-bottom type are more favorable to early attack by the fungus. Crowded stands, much shade and suppression, and a higher percentage of atmospheric and soil moisture all presumably contribute to the earlier infection in the stands situated along the river bottoms.

It is to be understood that the figures as given in the tables that follow are not to be taken as absolute. The small numerical basis for some of the data, especially in Table I and part of Tables II and III, and other sources of unavoidable error, make it plain that the figures given are to be interpreted as indicative of the true conditions and not as an absolute analysis. The general tendencies must first be ascertained and the methods for determining them developed before absolute figures are presented.

TABLE II.—Average annual increase in the volume of heart-rot in infected western hemlock trees of the several age classes, on plats of the river-bottom and southwestern-slope types.

Age class.	Average age.	Interval between age classes.	Average volume of rot (cubic feet).		Number of infected trees (basis).
			As measured.	Annual increase between age classes.	
River-bottom type:	Years.	Years.			
46 to 56 years.....	52		0.27	0	6
57 to 62 years.....	60	8	.55	.035	7
63 to 70 years.....	66	6	.82	.045	32
71 to 80 years.....	75	9	2.23	.16	39
81 to 90 years.....	86	11	3.62	.13	19
91 to 102 years.....	95	9	4.04	.05	7
104 to 126 years.....	114	19	4.21	.01	6
All age classes.....			2.25	.07	116
Slope type:					
54 to 70 years.....	62		.12		2
72 to 75 years.....	74	10	.31	.02	2
90 to 99 years.....	94	20	1.42	.06	6
101 to 120 years.....	110	17	14.31	.81	6
134 to 160 years.....	149	33	16.89	.07	9
162 to 179 years.....	172	23	19.16	.10	11
184 to 200 years.....	193	21	46.62	1.31	12
207 to 225 years.....	216	23	46.56	a .62	13
226 to 306 years.....	254	38	73.43	.71	12
All age classes.....			24.30	.46	73

a Interpolated.

RELATION OF DECAY TO SITE AND TO AGE.

Western hemlock, which ranges in decay from 50 to 100 per cent of trees infected in some localities and quite generally so over large areas where the species occurs in nearly pure stands, may be entirely free from its principal disease (heart-rot, caused by *Echinodontium tinctorium*) in some regions.

In order to determine the distribution of *Echinodontium tinctorium* and the extent of the damage produced by it as influenced by various environmental factors, a series of questions was prepared and submitted to the timber and mill owners in all parts of the Northwest. In response to a total of 151 letters sent out, 44 replies dealing with hemlock were received. A certain number of the replies were confined to grand fir alone. The replies to the questions were prepared by experienced scalers and cruisers, to whom the writers desire to express their thanks for the careful attention and willingness shown to further the progress of the investigation. In most cases the "conks" (figs. 1, 2, 3, and 4) of the fungus chiefly responsible for the decay in hemlock for the region were sent by the recipients of the letters. In practically every instance the fungus was *E. tinctorium*. Many of the northwestern regions not covered by these letters were visited; hence it was possible to gain a fairly accurate knowledge of the range and destructiveness of this disease along with the data on other phases of the study. Since the questions given out dealt with a variety of factors, the information thus obtained is submitted under the various sections of this paper covering the particular point under discussion. Four of the questions concerned the influence of site on the distribution and prevalence of decay.

The belief that conditions of soil, moisture, exposure, and altitude greatly influence the distribution and prevalence and the amount of decay caused by a particular fungus in the forest is supported by the data thus obtained. Out of 44 different observations covering a great range of territory, including the entire economic range of the tree in the United States, only three observers report a uniform distribution of decay in hemlock for all conditions. All other replies indicate great differences in the amount of heart-rot as influenced by soil, slope, and elevation. The topography and soil of those regions from which a uniform condition of defect is reported are so uniform in themselves that no great variation could be expected. The question of the influence of the site on the prevalence of the fungus *Echinodontium tinctorium*, it appears, depends on the moisture condition of the soil and its porosity and not upon soil quality. The fungus may occur on hemlock growing on any type of soil, but occurs to a greater extent on trees growing on wet, undrained sites. This is found to be true at any elevation, showing very clearly that the excessive moisture conditions of the site are highly favorable to the development of the principal attacking fungus. The answers indicate that the soundest hemlock is usually associated with a rich, well-drained soil. In wet, shallow soil the root system can not attain its normal position but must stay near the surface. If the soil is sufficiently loose to enable the roots to penetrate deeply, but is undrained,

as in semiswamp, bottom sites, decay is prevalent and a retardation of growth also results. No relation between the composition of the soil and the prevalence of the fungus has been observed. Hemlock growing on lime, sand, or clay soils as a base for the regular humus layer exhibits no greater proclivity to fungus attack than do other species. Of the total answers received, 41 stated definitely that the least defective hemlock was found at the upper elevations and slopes and upon well-drained soils. The most defective stands were en-

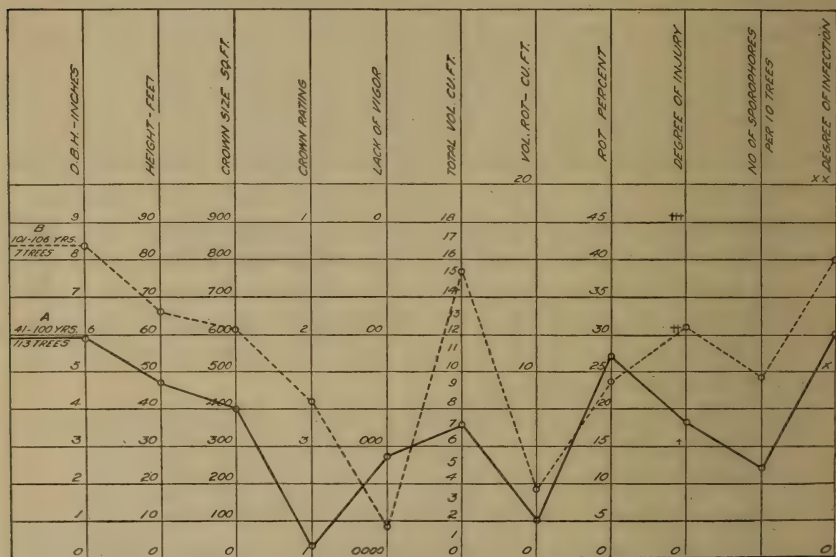


FIG. 11.—Diagram showing the relation of various factors to the age classes of western hemlock on plats of the river-bottom type.

countered at lower elevations, on flats and bottom sites, and upon poorly drained soils.

As the tree grows older it reaches a certain period in its life at which its vigor seems to have reached its maximum, after which time the vitality of the tree ebbs. This is often spoken of merely as old age and is the resultant lowering of vigor due to the increased unfavorable environment of its surroundings. Many factors enter into this relationship, competition with younger and sturdier trees for light, water, and food being the principal ones. Not the least of these factors is the effect of cumulative injuries received throughout its life. Many writers on forest pathology have expressed this opinion, and the data following (Table IV) convey a like conclusion. Von Schrenk¹ states that "it has been pointed out that as trees grow older they become

¹ Schrenk, Hermann von. Some diseases of New England conifers: A preliminary report. U. S. Dept. Agr., Div. Veg. Phys. and Path. Bul. 25, p. 51. 1900.

more liable to insect and fungus attack. An old tree has many vulnerable points, such as old branches and wounds," and naturally these injuries open the tree to more and greater infections. Hartig¹ does not believe that old age is a natural inherent condition, but says: "In itself, the feebleness of old age is not a natural condition attributable to internal causes. The older a tree is, so much the more numerous are the dangers through which it has had to pass, and so much the greater is the number of its injuries and wounds through which parasites and saprophytes can find an entrance into its inte-

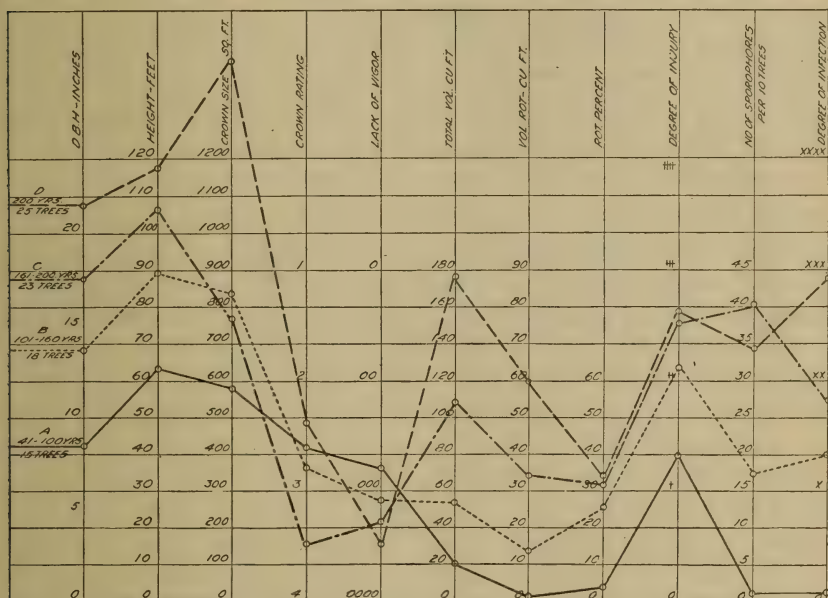


FIG. 12.—Diagram showing the relation of various factors to the age classes of western hemlock on plots of the southwestern-slope type.

rior." From the data secured by questions sent to a large number of lumbermen in the Northwest, it was found that a majority of the answers received indicated that the older age classes of hemlock were very much more defective than the younger. Möller² has shown that, with the increase of age in stands infected with *Trametes pini*, there was a corresponding increase in the percentage of trees infected, and the data given in Table III and figures 11 and 12 also show plainly that with increasing age there is a definite increase in the amount of decay.

¹ Hartig, R. Textbook of the Diseases of Trees. Translated by William Somerville, p. 7. London and New York, 1894.

² Möller, A. Über die Notwendigkeit und Möglichkeit wirksamer Bekämpfung des Kiefernbaumschwammes *Trametes pini* (Thore) Fries. In Ztschr. Forst. u. Jagdw., Jahrg. 36, Heft 11, p. 677-715, 2 pl. (partly col.). 1904.

TABLE III.—*Averages computed from field data relating to heart-rot in western hemlock based upon trees of the several age classes on plats of the river-bottom and south-western-slope types.*

Type and age classes.	Number of trees (basis).	Diameter breast high.	Height.	Crown size (height by width).	Crown rating.	Lack of vigor.	Volume (cubic feet).		Rot percentage.		
							Total.	Of rot.	For class.	For stand.	
										Total.	Infected trees.
River-bottom type:		<i>Inches.</i>	<i>Feet.</i>	<i>Square feet.</i>	<i>Degree.</i>						
41 to 100 years.	113	5.9	47.0	400.0	3.9	3.1	7.1	1.9	27.1	26.6	96.7
101 to 160 years	7	8.4	65.7	609.5	2.6	3.4	15.3	3.6	23.6		
Slope type:											
41 to 100 years.	15	8.4	62.6	574.2	2.6	2.8	19.8	.62	3.1	30.8	90.1
101 to 160 years	18	13.6	88.9	833.3	2.8	3.1	52.6	13.20	25.1		
161 to 200 years	23	17.5	106.0	761.6	3.5	3.3	107.6	33.50	31.1		
201 years and over.....	25	21.5	117.0	1,458.6	2.4	3.5	175.5	59.40	33.8		

From the viewpoint of the natural increase in heartwood due to larger size, etc., coincident with age, it is presumed that the amount of decay would increase proportionately. The figures obtained in the case of the southwestern-slope type show this to be not only true in this respect, but the proportion of the volume of decay to the total volume of the tree is also much higher. In the river-bottom site (Table III) the average volume of rot increases from 1.9 cubic feet in the 41 to 100 year age class to 3.6 cubic feet in the 101 to 160 year age class. In the southwestern-slope type (Table III) a better comparison between age classes can be made. Here a definite increase in rot volume from the 41 to 100 year age class to the 201 year and older age class is evident. Table II also shows an irregular increase in the average annual increase in rot volume between age classes, though the general trend of the figures in Table II shows a gradual increase from the younger to the older trees up to the age class 81 to 90 years, after which a gradual decline is noted. This fact might possibly reflect the rate of growth of the tree and therefore of the heartwood and indicate a dropping off in rot activity simultaneously with a slowing up of the annual growth.

RELATION OF DECAY TO VIGOR, CROWN RATING, SIZE, AND VOLUME.

Decay in western hemlock is the main factor of depreciation outside of fire. No other destructive agency operates upon this tree to cause so much waste and none is so difficult to control. The preceding data have shown how the tree, especially when growing in river-bottom sites, is subject to attack by this fungus at an early age, and for the youngest age classes the river-bottom type shows a greater average volume of rot than the southwestern-slope type. In the data secured from lumbermen of the Northwest it is found that a

high rate of decay is general in western-hemlock and grand-fir stands and especially so in low, poorly drained bottoms. The hemlock and also the grand fir reacts more favorably in the sites where the factors concerned in the growth of the tree are less favorable to the advance of the attacking fungus.

The relation which such factors as vigor, crown rating, size, and volume bear to the inception and progress of decay has never been thoroughly demonstrated. A difficult part of this task lies in obtaining comparable figures to indicate the rating for lack of vigor, the crown rating, the degree of infection, and the degree of injury. By standardizing these factors on numerical data, a basis for comparison has been secured. In the first part of Table III are arranged the averages of 120 trees, taken from the various plats worked as growing on the river-bottom site. In this table the total height represents a measurement from the ground to the tip of the tree. The crown size is given as the product of the height of the crown by the width. The crown rating and lack of vigor are determined from the field sheets, according to the standard outlines given. Similarly, the total volume and the volume of rot determine the rot percentage. In the column "Lack of vigor," the figures represent the relative numerical values, determined in the following manner: All trees (18) of the 101 to 160 age class were grouped together (second part of Table III). Three of these trees had a lack of vigor represented by 00, 10 trees by 000, and 5 trees by 0000. 3(00) equals 6(0), 10(000) equals 30(0), and 5(0000) equals 20(0), which gives a total of 56(0). This figure divided by 18 gives 3.1(0), which is indicated by 3.1. This gives a numerical basis for the relative values of lack of vigor in plotting the graphs. A similar method was applied to the data in the column under crown rating, and the results secured were used in the plotting of the graphs (figs. 11 and 12). This method was also used in the "Average degree of injury" column in Table IV and in plotting points for the graphs in figures 11 and 12.

The process was applied to the trees of the various plats which were growing upon the southwestern-slope sites, and the resulting data are arranged in the second part of Table III. Pathological graphs were then constructed from each of the two parts of Table III, using all the factors concerned and arranging the units in such a manner as to secure the least confusion in following the individual graphs. In the graph in figure 11, constructed from the figures relating to river-bottom plats in Table III, the first points to be noted are that the diameter, height growth, crown size, total volume, and volume of rot all increase with the increase in age. This is found to be true also in figure 12 (with the exception of crown size), which graphically expresses the data given for plats of the southwestern-slope type in Table III. In searching for those factors most prominent in their

relations to the degree of infection and included within the first eight factors of the graph, there is apparently no one which stands out. The factors of height, diameter, crown size, total volume, and lack of vigor show increase with increased age, so that no special importance can be attached to these in so far as any one directly influences the rate of decay. The data herein given are not sufficient proof that vigor is the one outstanding factor influencing decay; since vigor is expected to decrease with increased age, the parallelism of increased decay and decreased vigor can not be interpreted as a direct influence exerted by vigor. No doubt vigor plays an important part in the speeding up or slowing down of the rate of decay in a tree, if only this relation could be determined accurately and definitely.

The total rot percentage for the entire stand of the bottom type is 26.6, as compared with 30.8 per cent for the slope type. This slight difference in the percentage of total rot for the two types (where a greater difference might be expected) is significant and is no doubt due to the fact that under each site are grouped all the trees, ranging from the youngest to the oldest. A comparison of the percentages of infected and uninfected trees for the two sites shows a striking difference in results from different methods of presenting the amount of infection in a stand. In the river-bottom type, 97 per cent of the trees were infected and 27 per cent of the wood decayed. In the slope type, 90 per cent of the trees were infected and 31 per cent of the wood decayed. A comparison of these figures indicates that ease of infection is the factor in which the bottom type exceeds the slope type and the rate of spread of decay in the trunk is less speeded by bottom location, if at all. The latter belief seems to be borne out by the fact that the rate of spread in the bottom type must necessarily have been slow, since the stand was composed of comparatively young trees of small heartwood content.

In the slope type the environment is favorable to the full development of tree growth, with an environment equally unfavorable to the development of fungi. The reverse is true of the river-bottom type. This is evidenced by the facts brought out in Table III (figs. 11 and 12), which show that decay is more pronounced in the river-bottom type than in the other. The graphs also show that in the 41 to 100 year age class (Table III) the conditions for the best development of the health of the trees were far below those for the 101 to 160 year age class.

RELATION OF DECAY TO INJURY AND TO SPOROPHORES.

The relation of injuries to decay in respect to furnishing entrance points for infection has been accepted with little opposition, and in many instances in culturing fungi it has been found that the opening

of the protective tissues of the host plant was necessary in order to produce infection. A portion of the field data was obtained with the principal object of determining the part played by the degree of injury. All injuries were noted as to size, height on tree, side of tree affected, total number, and condition (whether healed or not healed); whenever possible the age when the injury was inflicted and the time taken to heal were also noted. A special effort was made to determine, if possible, the particular injury causing the original infection. This was generally taken to be at the point on the trunk where the oldest sporophore appeared. Table IV gives summaries for the river-bottom and southwestern-slope types, respectively, based upon an age-class division of the trees.

TABLE IV.—*Relation of injuries causing heart-rot to the age and to the total stand of western hemlock trees on plats of the river-bottom and southwestern-slope types.*

Type and age class.	Infection traced to—								Uninfected trees.		Average degree of injury.	Number of trees.
	Branch stubs.		Frost cracks.		Broken tops.		Miscellaneous injuries.					
	Number of trees.	Per cent.	Number of trees.	Per cent.	Number of trees.	Per cent.	Number of trees.	Per cent.	Number.	Per cent.		
River-bottom type:												
41 to 100 years.....	103	91.2	1	1.0	3	2.6	2	1.7	4	3.5	1.19	113
101 to 160 years.....	7	100.0	0	.....	0	.....	0	.....	0	.....	2.05	7
Total.....	110	92.5	1	.1	3	2.5	2	1.6	4	3.3	1.14	120
Slope type:												
41 to 100 years.....	9	60.0	1	6.7	0	.....	0	.....	5	33.3	1.3	15
101 to 160 years.....	12	66.6	0	.....	1	5.7	2	11.1	3	16.6	2.1	18
161 to 200 years.....	16	70.0	1	4.0	3	13.0	3	13.0	0	.....	2.5	23
201 years and older.....	22	88.0	0	.....	2	8.0	1	4.0	0	.....	2.6	25
Total.....	59	72.8	2	2.6	6	7.4	6	7.4	8	9.8	2.1	81

^a Windfall scars.

Table IV shows that by far the greatest percentage of infection was attributed to branch stubs (figs. 6, 7, and 8).

This amounted to 92.5 per cent in the river-bottom type and 72.8 per cent in the slope type for the total stand in each type. Broken tops come second, and miscellaneous injuries, such as windfall and logging scars, etc., reached a percentage of 7.4 in the slope type and 1.6 in the river-bottom type. Grouped under miscellaneous causes were such injuries as blazes, logging, windfall and fire scars, lightning, etc., and a considerable amount of sapsucker injury. The first infection was not attributed to a certain injury unless the development of a sporophore on it (fig. 2) showed this to be the most apparent point of infection. The relative degree of injury as determined upon a basis of age class is shown in figures 11 and 12, taken from Table IV under the head of "Average degree of injury." This shows an increase

in degree of injury with an increase in the degree of infection and with increased age. With increase in age the cumulative chances for infection due to injuries of all kinds, and especially to branch stubs, increase appreciably, and it is but natural that the older trees bearing many injuries and a high degree of injury should show an equally high degree of infection.

The two types of stand compared on the basis of the amount of injury are found to vary but little in the general relation between the degree of infection and the degree of injury. In both types the groups of higher rot percentage also show a higher degree of injury, and similarly the groups of lower rot percentage show a smaller degree of injury. In both sites the infections traced to branch stubs bore the largest percentage and the frost cracks the smallest. Broken tops in both instances came second in importance.

In the southwestern-slope type (Table IV), the percentage attributed to broken tops was larger than in the river-bottom type (Table IV), due to the more exposed location and to the older stand. Infections traced to branch stubs in the slope type equaled 72.8 per cent of the total, while in the river-bottom type it equaled 91.5 per cent. It would appear that in spite of the younger age class the river-bottom type developed more infection-producing branch stubs than the other. A reason for this may be found in the fact that the crowded, suppressed condition of the river-bottom stand was much more favorable to the infection of branch stubs than the other more open type of stand. The high proportion of branch-stub infections to injury infections can be partly explained by the fact that the trees of the river-bottom type, being younger, had fewer injuries.

In the slope type the largest amount of injury was found in the oldest age class (201 years and older), and in the river-bottom type it was also found in the older age class (101 to 160 years). In the slope type 10 per cent of the trees were uninfected, and in the river-bottom type a much smaller percentage (3) was uninfected, showing by this comparison a more favorable environment for the attacking fungus in the river-bottom sites.

The slope type exhibited more frost cracks, broken tops, and miscellaneous injuries to the stand than the river-bottom type, which is due partly to the older age and partly to the more exposed situation. The wind plays an important part in both the formation of frost cracks and in the broken-top condition of many of the trees. It was particularly interesting to note that most of the oldest and largest frost cracks were found to have formed in the hollows between the root spurs. This seems to be more general in the slope type, where the exposure to high winds and the height of the trees (in connection with low temperature) appears to play an important part in their

formation. The swaying of the trees by the wind when the low temperature has set up a stress within the tissues of the lower trunk would cause the cracks to form at right angles to the swaying movement and in the root-spur hollows, where the least resistance to splitting was to be encountered. The swaying of the tree alone sets up varying forces of strain and rupture in the lower part of the tree, and when the tissues are contracted or prevented by low temperatures from adjusting themselves, a frost crack eventually occurs.

Sporophores of fungi, if they develop at all, appear after a certain period has elapsed from the time of first infection. This period, up to the present time, has not been determined for most of the xylophilous fungi, at least not for *Echinodontium tinctorium*. Such determination would involve a considerable amount of careful inoculation work upon trees absolutely free from fungous infection, which in the case of wood-destroying fungi would extend over a period of several years. The relation which sporophores bear to the development of decay in the host and to the degree of infection can more easily be determined. A careful field study of the tree in question with reference to recording all possible data relating to the sporophores has developed several interesting facts. Little work has been done along this line tending to give actual figures as a basis for conclusions. The data collected are grouped under the two parts of Table V for the river-bottom and slope types, respectively. Under the heading "Position on tree," the sporophores were grouped to indicate whether the northerly growing sporophores were more numerous than those growing on the southerly side of the tree. The remaining columns in Table V are self-explanatory with the exception of the column headed "Relative position along trunk." This refers to the vertical position of the largest sporophore with respect to the other sporophores on the same tree. For example, tree No. 50 had a total of five sporophores, of which the third one from the ground was the largest. This condition was expressed by the figures 3-5, indicating that the position of the largest sporophore was in the center of the group. This method was used throughout, and the resulting figures were used to determine whether the largest sporophore was found more commonly in the center or toward either end of the group.

The river-bottom type with reference to its sporophore data (Table V) is in general very similar to the slope type. Out of a total of 119 trees, 70 (59 per cent) were sporophore-bearing trees. On these 70 trees a total of 149 sporophores were found, of which 131 (88 per cent) were living and 18 (12 per cent) were dead, giving an average of 1.8 live sporophores to a tree and 1 dead sporophore to every 4 trees. These figures show a much larger percentage

of live sporophores than those of the slope type. Almost all (96 per cent) of the largest were living, which was equally true of the sporophores in general. The average height from the ground is 8.7 feet. The northwest to north-northeast grouping held 53 per cent of the total sporophores, the southwest to south-southeast grouping 27 per cent, the east 9 per cent, and the west 11 per cent. Most of the sporophores are grouped on the northern aspect of the trunks, with a smaller percentage on the southern. Upon dividing the sporophores into groups corresponding to the eight principal points of the compass, it was found that most of them (23 per cent) were on the northwest side, the next largest on the south (18 per cent), and the smallest number on the southeast (3 per cent).

The figures in Table V, river-bottom type, relative to the number of sporophores are plotted in figure 11 and show the relation between the degrees of infection and the number of sporophores. To avoid the awkwardness of using such an expression as "1.3 sporophores" in the diagrams, it was thought proper to term this factor "Number of sporophores per 10 trees" and use the same figures after multiplying each by 10. This does not alter the comparative value of the figures. These data and the pathographs indicate how the increase in the number of sporophores keeps pace with the increase in the degree of infection.

In the southwestern-slope type (Table V), out of a total of 81 trees 54 (67 per cent) bore sporophores in varying numbers. These 54 trees carried a total of 210 sporophores, of which 141 (67 per cent) were alive and 69 (33 per cent) were dead, giving an average of 2.6 live and 1.2 dead sporophores per sporophore-bearing tree. More than half (60 per cent) of the largest were living. These data indicate that the number of sporophores increases with increased age and with increase in the degree of infection as expressed by the rot percentage. This holds true for all the age classes except the oldest, which is found to have a smaller total number of sporophores and a smaller number per 10 trees than the 161 to 200 age class. This may be due to the fact that the maximum sporophore production has been reached in the 161 to 200 age class and to the further fact that on old trees the older sporophores are often found to have dropped to the ground. An average of all the figures relative to the vertical position of the largest sporophore gave a figure which placed it at or very near the middle point. This would seem to indicate that the decay spreads more or less in both directions up and down the trunk from the point of original infection; consequently the sporophores are produced on either side of the largest as the decay progresses. This is, of course, not true in every case, but the average condition is found to be such.

TABLE V.—Summary of sporophore data relating to heart-rot of western hemlock trees on flats of the river-bottom and southwestern-slope types.

Age class.	Sporophores.										Infection traced to—									
	Number of trees (basis).	Number of trees bearing sporophores.	Number alive.	Number dead.	Total number.	Average number per tree.	Largest.			Smallest.	Position on tree.									
							Average age.	Condition.	Size.		Relative position along the trunk.	Size.	Average height.	Northwest to north-north-east.	Southwest to south-south-east.	East.	West.			
River-bottom type: 41 to 100 years.... 101 to 160 years....	112 a 7	64 6	118 13	14 4	132 17	1.2 2.4	Yrs. 6.6 10.0	61 6	3 0	Inches. 9 by 6 by 4... 8 by 6½ by 3...	Lower. Middle.	Inches. 1 by 1 by 1... 3 by 2½ by 1½	Feet. 8.3 13.1	67 12	38 3	12 1	15 1	Broken tops.	Frost cracks.	Miscellaneous Injuries.
Total (Number... Average per sporophore-bearing tree.	119	70	131 87.9 1.80	18 12.1 b .25	149 2.1		c 7	67 95.7 All.	3 4.3	9 by 6 by 4... 5 by 3½ by 2½	(d)	1 by 1 by 1...	8.7	69 53 (c)	41 27	13 9	16 11	2	1.7	0.9
Slope type: 41 to 100 years.... 101 to 160 years.... 161 to 200 years.... 201 years and older	15 18 23 25		1 21 63 56	0 10 29 30	1 31 92 86	.07 1.70 4.00 3.40	9.0 8.5 15.1 12.8	1 9 10 13	0 2 10 9	8 by 5 by 3... 9 by 5 by 5... 16 by 8 by 8... 11 by 11 by 5...	Middle. do. do. do.	3 by 3½ by 1... 3 by 3 by 2... 3 by 3 by 2... 3 by 2 by 2...	9.5 30.6 40.4 45.3				1 5 16 23	1 0 4 2		2 2
Total (Number... Average per sporophore-bearing tree.	81	54	141 67.1 2.6	69 32.9 1.3	210 4.0		f 13	33 61.1 All.	21 38.9	16 by 8 by 8... 7 by 6 by 4...	Middle. Middle.		39.9	80 38.1 (c)	57 27.1	28 13.3	45 21.5	7 9.6	2 2.8	4 5.4

a Sporophore data lost on one tree, which therefore was not included.

b One to every four trees.

c Average age of largest sporophores.

d Between middle and lower.

e All northerly.

f Average age of largest sporophores.

The distance from the ground of the largest sporophore ranges from 4.5 feet in the case of younger suppressed trees to 78.5 feet in the case of a large 300-year-old veteran. The average height indicated 39.9 feet. The grouping of the sporophores in respect to their cardinal positions on the tree gave some very interesting figures. The largest number of the sporophores (38 per cent) was found in the northwest to north-northeast grouping, 27 per cent in the southwest to south-southeast, and 21.5 and 13.5 per cent in the west and east groupings, respectively. Upon dividing the sporophores into groups corresponding to the eight principal points of the compass, it was found that 25 per cent were on the north side, the next largest on the west (21 per cent), and the smallest number on the southwest (4 per cent). The data for the slope type show the largest number on the northerly side of the tree. No such overwhelming percentage was secured as in the work of Möller,¹ who assembled data on the sporophores of *Trametes pini* (Brot.) Fr. and found that 45.8 per cent of the sporophores appeared on the west side of the tree and 89.4 per cent on the westerly side. This westerly side included all sporophores listed in the north, south, and west columns.

Figure 12, the southwestern-slope type, represents in the respective column the sporophore data taken from Table V. The same relation is found to exist between the degree of infection and the total number of sporophores as is found in the river-bottom type. The number of sporophores per 10 trees ranges from 13 in the 41 to 100 age class to 24 in the 101 to 160 age class, exhibiting a considerable increase between the two. In the slope type a similar rate of increase can be noted, which is constant between all the age classes except the two oldest.

THEORY OF INFECTION.

Suppression caused by shade combined with a crowded condition of root spacing as well as crown spacing tends to reduce vigor appreciably. A poorly drained soil having a large amount of soil moisture is another factor to be considered in this connection.

Upon the vigor of a tree depend all its vital functionings, its ability to enlarge and elevate its crown toward better lighting, to secure raw material and manufacture food, to compete with its neighbors, to quickly heal wounds, and to resist attack by fungous enemies. The predisposition or inherent susceptibility of a tree to disease is not considered a sufficient cause for the extensive attack and development of a fungus in that tree. It is believed that low vigor or a

¹ Möller, A. Über die Notwendigkeit und Möglichkeit wirksamer Bekämpfung des Kiefernbaumschwammes *Trametes pini* (Thore) Fries. In Ztschr. Forst. u. Jagdw., Jahrg. 36, Heft 11, p. 677-715, 2 pl. (partly col.) 1904.

natural weakness in healing injuries, producing resin, etc., combined with environmental factors is responsible for the intensive and extensive fungous activity within this species of tree. At the same time it must be borne in mind, especially in the case of hemlock, that such a natural trait as the absence of any great amount of protective resin must be considered as playing an important part in the entrance of the disease. The foregoing data have clearly shown that one fungus is responsible for almost the entire amount of heart-rot found in western hemlock, that the river-bottom type exhibits more decay than the other (comparing the youngest age class), that this type also exhibits a remarkably early decay, and that as a whole a large amount of heart-rot is found in hemlock at early periods in its life.

Dense stands growing in moist, poorly drained soils develop a large number of suppressed or low-vigor trees. This is more commonly the case when the stand is overtopped by older trees of other species. The low vigor due to the overshadowing of the lower crown causes the early and numerous formation of shade-killed branches. These in time produce branch stubs which are believed to be responsible for most infections by *Echinodontium tinctorium*. The shading of the crown, especially the lower crown, not only causes the eventual formation of branch stubs but produces a moisture and shade condition favorable to the germination and entrance of the fungus. As a theory of infection for hemlock types, this is corroborated by the fact that in thinnings made by cutting out the more merchantable species the secondary crowns formed rapidly and vigorously by an enlargement and thickening of the regular crown. This fact, coupled with the observation that very few living sporophores were found 10 years after the thinning, strengthens the theory.

DISCUSSION OF RESULTS.

As a preliminary to the discussion of the main points brought out in the foregoing pages, it is essential to review briefly the main silvicultural characteristics of the tree in question. It will then be easier to point out the importance of the various factors influencing decay and to arrive at certain conclusions regarding the action of the fungus *Echinodontium tinctorium* during its life history on the host.

The western hemlock, as indicated by its distribution, requires a cool and moist climate for its development, and an important fact in this connection is its splendid maximum development along the western slope of the coast ranges, where it receives an annual rainfall of from 70 to 100 inches.¹

¹ Allen, E. T. The western hemlock. U. S. Dept. Agr., Bur. of Forestry Bul. 33, p. 10. 1902.

Its moisture requirements seem to be the principal limiting factor of its distribution, since it is found growing on a variety of soils. Its altitudinal range extends from sea level in Alaska, British Columbia, Washington, and Oregon to an altitude of 6,000 feet, and in Idaho and western Montana it is found at a maximum altitude of 5,000 feet. It is always at its best in cool moist draws or north slopes. Regions with a relatively high humidity favor its development, although at some of the higher altitudes the humidity is much less than in the bottom-land sites.

A very tolerant species, it is found to thrive in Idaho and Montana in the white-pine type, generally in a mixed stand. Referring to its tolerance, Sudworth¹ says it is "very tolerant of shade throughout life, especially in seedling stages. In later life vertical light is necessary for best growth. Allowed overhead light, it recovers remarkably well from long suppression and renews rate of growth. Prolonged suppression in dense shade greatly checks growth. It thrives in cool, open, humid places with abundant soil moisture."

No natural thinning takes place under normal conditions, and in mixed stands the pruning of the lower branches is a slow and imperfect process. Shade causes the lower branches of the crown to die, and these remain on the trunk until broken by wind, windfalls, or other causes. This condition leaves the tree with a large number of branch stubs open to infection by fungous spores.

Hemlock in its green condition contains 40 to 60 per cent of its own dry weight of moisture,² a relatively large amount compared to the other trees of the region. This fact has a direct bearing upon the action of the fungus in the heartwood and accounts for the water-logged condition of the base of the tree which is often encountered in stands growing on poorly drained soils.

In summing up the points brought out by this study the most pronounced results are found in the variations in the action of the decay in the two types studied. A glance at the plat descriptions given for each type (Table I) will show the variation in slope and exposure as well as the marked difference in soil and atmospheric moisture. The river-bottom type, growing as a dense suppressed stand on a heavy undrained soil in close proximity to the river and to its numerous sloughs, presupposes its greater susceptibility to the attack of the fungus. In the absence of trees of an older age class it can only be assumed that the rot percentage would increase with age. The fact that the rot percentage in the older age class was lower does not invalidate this assumption in view of the small number of trees it

¹ Sudworth, G. B. *Forest trees of the Pacific Slope*, p. 95. 1908. Published by U. S. Department of Agriculture, Forest Service.

² Hanzlik, E. J., and Oakleaf, H. B. *Western hemlock; its forest characteristics, properties, and uses*. In *Timberman*, v. 15, no. 12, 1914, p. 25-33, tab. 3.

contains. The total percentage of infected trees as well as the total rot percentage of this type in comparison to the slope site bear out this statement (Table III). The relation of moist sites to the degree of infection of a stand has been noted by Hartig,¹ who says: "The climatic conditions peculiar to a given district may render it especially liable to outbreaks of certain diseases. Thus, in alpine districts proximity to lakes and narrow valleys specially predisposes to certain fungoid diseases, because the moist air of such places favors the fructification of fungi in a high degree." The loss of vigor due to the unfavorable environmental conditions and principally due to suppression by shade is responsible to a certain extent along with other factors in the rapid and universal spread of the decay on this site. Meinecke² states: "The relative extent of decay by *Echinodontium tinctorium* is far greater in slow-growing, suppressed white firs than in thrifty ones." And in discussing the susceptibility of hemlock to injury Hanzlik and Oakleaf³ state: "Broken branches and injuries to the bark account largely for the spread of conk (*Trametes pini*) and the stringy brown-rot (*Echinodontium tinctorium*), these being more abundant in overmature stands and in suppressed stands overtopped by mature growth."

That on the river-bottom type the trees are decayed at an earlier age, is brought out by a comparison of the data given. The river-bottom type in comparison with the slope type exhibits not only extensive decay at an earlier age and a younger age of infection but a larger number of branch stubs and sporophores for similar age classes for the stand. The data secured from the lumbermen of the north-western region also aid in determining the fact that hemlock is more defective on lower elevations, on bottom or flat sites, and on poorly drained soils.

In making use of pathological data in the determination of pathological cutting ages for a stand, the rot percentages as given here for separate age classes of the stand are of some value. With the rot percentages as a basis (indicating the ratio of the rot volume to the total volume of the stand for each age class), the forester can determine a cutting age for that stand, using all the economic and silvicultural factors to aid him in a correct determination. The average annual increase in rot volume between age classes can also be used to advantage in determining the rapidity of increase in rot volume. Forest pathology can thus serve to furnish pathological data for particular stands, which data can be applied by the practical forester

¹ Hartig, R. Textbook of the Diseases of Trees. Translated by William Somerville, p. 10. London and New York, 1894.

² Meinecke, E. P. Forest-tree diseases common in California and Nevada, p. 27. 1914. Published by U. S. Department of Agriculture, Forest Service.

³ Hanzlik, E. J., and Oakleaf, H. B. Op. cit.

in a solution of such forest-regulation problems as are appreciably influenced by the presence of decay in the stand. When once the forester reaches the point in his calculations upon a proposed sale where he can determine a certain rot percentage as the maximum to be considered in a stand in order to secure the required amount of sound material at a minimum cost, with this rot percentage as a basis it will be comparatively easy to compute the cutting age of that stand.

METHODS OF CONTROL.

The methods of control applicable to such types as are here under discussion can be little other than extensive. The foregoing data, owing to the small number of trees included in some of the age classes and to apparently unavoidable errors, are not to be taken as exact in determining the cutting age but are given merely as an aid to this determination. Intensive control methods can not be applied to logging operations where extensive logging methods are practiced. Methods such as can be readily incorporated into the usual routine of logging operations and conforming to the practice of the Forest Service are the only ones which can hope to fill the need for forest sanitation among the all-practical lumbermen and foresters. Intensive control can be practiced to a limited extent only upon such sales areas as warrant the additional cost.

The control of wood-destroying fungi is not a matter comparable to the curative treatment of human disease, but is solely dependent for its success upon prevention. With few exceptions there is no help for a stand after it is once attacked by the fungus; hence, if preventive measures are to be effective they must precede the infection, or at least precede the period when the production of spores endangers the remaining healthy trees. There are several methods applicable to the hemlock type, and these can be grouped under two heads, sanitation clauses in timber sales¹ and pathological rotations. Under the first come such suggestions as girdling, killing by burning of infectious cull material and piled brush, thinning, and the direct cutting and burning of infected material. Under the second appear such methods based upon a study of the area in question as would lead to a cutting cycle aiming to secure the maximum amount of sound material with a minimum risk of future infection and at a minimum of cost. Each particular sale area has its individual variations affecting the pathological condition of the stand. The species in the mixture and the relative percentage of each, the slope and exposure, the moisture conditions, the cost of logging, the value of the species in the stand (in fact, all the environmental and economic factors) have to be taken into consideration before an attempt can be made to determine a method of control.

¹ Meinecke, E. P. Op. cit., p. 62. 1914.

A pathological survey of sales areas made with the object in view of determining the best method of incorporating sanitation clauses or of establishing pathological cutting ages would be an important step toward a practical and effective means of reducing the total amount of good timber going to waste every year in our forests. Girdling by the ax as a method of removal of infected trees left standing on a sale area is not to be recommended as an effective means of control. If the situation allows of no better method, then the girdling should proceed, the utmost care being exercised in severing all the transporting tissues. The recuperative ability of hemlock in regard to the healing of wounds is very great (fig. 13). Merely cutting a cleft in the outer sapwood, leaving the chip in

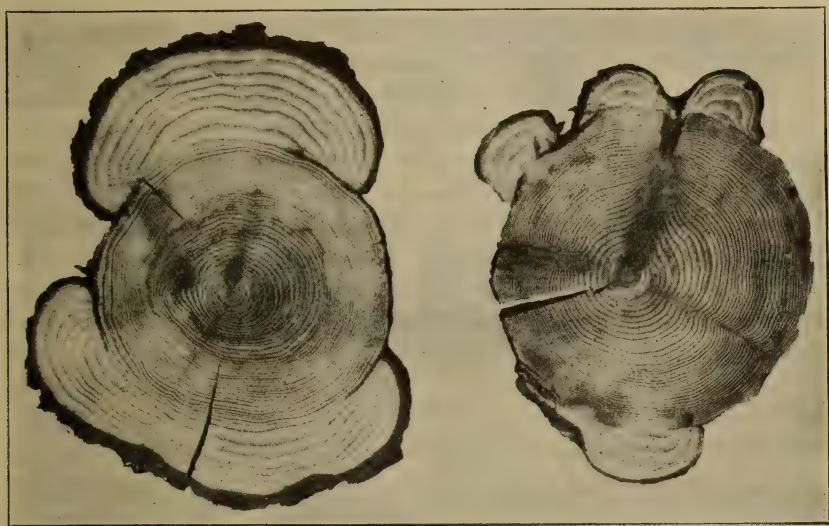


FIG. 13.—Cross sections of grand fir (at left) and western hemlock (at right), showing the result of imperfect girdling by the use of an ax.

place, will not suffice. The wound is very apt to heal, and even if it does not the tree may continue to live for years because the transporting tissues have not been actually severed. It is to be remembered that the wood of hemlock, owing to its nonresinous nature, probably retains its ability to conduct water and food substances longer than that of many of its associates; hence it will be found necessary to insist upon thorough girdling. Some notable instances of the longevity of even thoroughly girdled hemlocks and firs have come to notice in which the trees continued to live for five to eight years although the bark and part of the wood had been removed entirely around the tree for a foot or more. Trees under the shock of this wounding will sometimes produce as much seed in the year following as during several years of normal life. This point is im-

portant in connection with the girdling sometimes done for the purpose of removing seed trees of undesirable species.

In view of the need of a rapid destruction of fungus-infected trees, viz, those that may not be considered safe to leave on sales areas, there is much in favor of burning the trees severely and allowing them to stand. Girdling trees by fire is an old and successful practice. There should be sufficient loppings from the other merchantable trees that when piled about the base of the hemlocks and burned will effect their death without much injury to the forest soil or to the seeds of desirable species which may be embedded in the soil.

Thinnings whenever conformable to the conditions of the sales areas are of importance in greatly increasing the vigor and therefore presumably the ability to resist fungus attack in the remaining infected trees, and apparently reducing the number of viable and spore-producing fruiting bodies produced.

Under certain conditions where it is found practicable, a method of control by fire can be very effectively used. It has been observed that in cases where the down logs of hemlock were left in a sufficiently shaded and moist situation sporophores of *Echinodontium tinctorium* were developed, which were a source of infection to the remaining stand. The cutting of all infected trees and the piling and burning of all infectious cull material along with the brush will not only remove the fungus-infected wood but will prevent the formation of infection-spreading sporophores.

SUMMARY.

Western hemlock, a tree subject to prejudice by lumbermen and now beginning to find its place in the lumber markets, is abundantly distributed throughout the northwestern United States and western Canada.

It is found to be subject to a large percentage of decay, which is partly accountable for the prejudice against it.

Echinodontium tinctorium E. and E., the Indian-paint fungus, is responsible for practically all the decay in standing timber of western hemlock, causing a stringy brown-rot of the heartwood which extends to all parts of the tree.

In general, the sites and associations of western hemlock are favorable to the development of decay, and the moisture relation seems to play an important part in this respect. The absence of large quantities of resin, the tolerant habit of the species, the early and abundant formation of branch stubs, and the large number of spores produced yearly—all these are important factors in the rapid and extensive development of decay in the stand.

The fungus enters mainly through branch stubs. Frost cracks play a minor part as first-infection injuries. From the point of first infection, apparently coincident with the largest sporophore, the decay extends up and down the heartwood until all the susceptible heartwood is attacked. The extent of decay is found to increase with age. A high degree of injury, large numbers of sporophores, low vigor, and smaller crown sizes appear to develop more or less parallel with the increase in decay.

The environmental factors in the river-bottom type are more favorable to the early and extensive development of decay. A large percentage (97) of the total trees of the northern Idaho plats examined were found to be infected. Of 10 trees less than 60 years old and 3.5 inches in diameter breast high, 9 were infected.

The environmental factors in the southwestern-slope type are less conducive to early decay. The maximum development of the fungus is not reached until the stand is old.

A large number of sporophores are produced on both sites, the river-bottom site on a comparison basis of age class showing the greater number. The 48 trees over 160 years of age bore an average of 3.7 sporophores per tree.

Pathological cutting ages based upon data secured by thorough pathological surveys and adjusted to the economic factors concerned, if applied to all stands of hemlock, would aid greatly in checking the spread of the disease and would determine the cutting age of the stand before the increase in rot became too great for economic logging. In the present study this could be applied to the slope type only, since the trees of the river-bottom type are all below merchantable size.

A rigid sanitation clause inserted in all timber-sale contracts involving western hemlock should be aimed principally at the destruction by fire of all infectious cull material as well as all infected trees left standing. Girdling by the ax is not recommended.

These two control methods, when adapted to the situations they best serve, will pave the way to the sanitation of the western hemlock stands as well as other types of forests in the Northwest.

THE PRESIDENT TO THE FARMERS OF AMERICA.

[Extracts from President Wilson's message to the Farmers' Conference at Urbana, Ill., January 31, 1918.]

The forces that fight for freedom, the freedom of men all over the world as well as our own, depend upon us in an extraordinary and unexpected degree for sustenance, for the supply of the materials by which men are to live and to fight, and it will be our glory when the war is over that we have supplied those materials and supplied them abundantly, and it will be all the more glory because in supplying them we have made our supreme effort and sacrifice.

In the field of agriculture we have agencies and instrumentalities, fortunately, such as no other government in the world can show. The Department of Agriculture is undoubtedly the greatest practical and scientific agricultural organization in the world. Its total annual budget of \$46,000,000 has been increased during the last four years more than 72 per cent. It has a staff of 18,000, including a large number of highly trained experts, and alongside of it stand the unique land-grant colleges, which are without example elsewhere, and the 69 State and Federal experiment stations. These colleges and experiment stations have a total endowment of plant and equipment of \$172,000,000 and an income of more than \$35,000,000, with 10,271 teachers, a resident student body of 125,000, and a vast additional number receiving instruction at their homes. County agents, joint officers of the Department of Agriculture and of the colleges, are everywhere cooperating with the farmers and assisting them. The number of extension workers under the Smith-Lever Act and under the recent emergency legislation has grown to 5,500 men and women working regularly in the various communities and taking to the farmer the latest scientific and practical information. Alongside these great public agencies stand the very effective voluntary organizations among the farmers themselves, which are more and more learning the best methods of cooperation and the best methods of putting to practical use the assistance derived from governmental sources. The banking legislation of the last two or three years has given the farmers access to the great lendable capital of the country, and it has become the duty both of the men in charge of the Federal-reserve banking system and of the farm-loan banking system to see to it that the farmers obtain the credit, both short term and long term, to which they are entitled not only, but which it is imperatively necessary should be extended to them if the present tasks of the country are to be adequately performed. Both by direct purchase of nitrates and by the establishment of plants to produce nitrates, the Government is doing its utmost to assist in the problem of fertilization. The Department of Agriculture and other agencies are actively assisting the farmers to locate, safeguard, and secure at cost an adequate supply of sound seed.

The farmers of this country are as efficient as any other farmers in the world. They do not produce more per acre than the farmers in Europe. It is not necessary that they should do so. It would perhaps be bad economy for them to attempt it. But they do produce by two to three or four times more per man, per unit of labor and capital, than the farmers of any European country. They are more alert and use more labor-saving devices than any other farmers in the world. And their response to the demands of the present emergency has been in every way remarkable. Last spring [1917] their planting exceeded by 12,000,000 acres the largest planting of any previous year, and the yields from the crops were record-breaking yields. In the fall of 1917 a wheat acreage of 42,170,000 was planted, which was

1,000,000 larger than for any preceding year, 3,000,000 greater than the next largest, and 7,000,000 greater than the preceding five-year average.

But I ought to say to you that it is not only necessary that these achievements should be repeated, but that they should be exceeded. I know what this advice involves. It involves not only labor but sacrifice, the painstaking application of every bit of scientific knowledge and every tested practice that is available. It means the utmost economy, even to the point where the pinch comes. It means the kind of concentration and self-sacrifice which is involved in the field of battle itself, where the object always looms greater than the individual. And yet the Government will help and help in every way that is possible.

It was farmers from whom came the first shots at Lexington, that set aflame the Revolution that made America free. I hope and believe that the farmers of America will willingly and conspicuously stand by to win this war also. The toil, the intelligence, the energy, the foresight, the self-sacrifice, and devotion of the farmers of America will, I believe, bring to a triumphant conclusion this great last war for the emancipation of men from the control of arbitrary government and the selfishness of class legislation and control, and then, when the end has come, we may look each other in the face and be glad that we are Americans and have had the privilege to play such a part.

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WM. A. TAYLOR, Chief



Washington, D. C.

PROFESSIONAL PAPER

November 10, 1919

A STUDY OF THE ROTS OF WESTERN WHITE PINE.

By JAMES R. WEIR, *Forest Pathologist*, and ERNEST E. HUBERT, *Scientific Assistant, Office of Investigations in Forest Pathology, Bureau of Plant Industry, Missoula, Mont.*

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LOSSES DUE TO FUNGI.

The estimated stand of western white pine (*Pinus monticola*) in British Columbia, Oregon, Washington, Idaho, and Montana is about 23,685 million feet B. M., valued at approximately \$102,875,000. The average loss due to the activities of fungi in western white pine for the entire white-pine belt, based on data from logging operations in northern Idaho, is 1,658 million feet B. M.¹ This figure, on a basis of the above given valuation, shows a loss of \$7,201,250 from this cause alone. These figures, taken as an average condition throughout the merchantable range of the species, indicate the loss from decay to be enormous. The limited area occupied by merchantable white pine, the adaptability of its wood to a wide range of uses, and the ease with which it is worked so establish its value as a timber tree that it becomes imperative to investigate any cause of financial loss in the species, the amount of this loss, the

¹ Based on the recorded data, which give 6.9 as the average rot percentage for the entire area upon which the data were collected. The actual loss due to rot would no doubt be greater if figured on a basis of cull percentage or actual volume discarded, according to scalers' practice.

relation of various factors to the rots, and the means by which the loss may be reduced. This, in short, states the purpose of this bulletin.

LOCAL PATHOLOGY OF WESTERN WHITE PINE.

With the exception of the principal fungus (*Echinodontium tinctorium*) attacking western hemlock and grand fir, all fungi occurring on other trees of the western white-pine type attack white pine to a greater or lesser degree. Until it is determined that the interrelations of these fungi vary with different species of trees the conditions for fungous development may be considered very favorable. The western white-pine type of forest is described as having western white pine as the key tree and forming approximately 15 per cent or more of the stand. In some parts of its range (northern Idaho) in young stands western white pine forms as much as 50 per cent or more of the stand. The other species in the mixture are grand fir and western red cedar, the predominant trees of the type, and Douglas fir, western larch, western yellow pine, and lodgepole pine. In many of the mixtures of the western white-pine type, the white pine, although intermediate as to tolerance, very rapidly gains on its associates and eventually overtops them or may even drive them from the stand. One of the results of this suppression of associate species is to promote the activities of fungi in the associate species, which in turn react on the white pine. Fully stocked or even pure stands of western white pine may be found extensively attacked. In the fully stocked stands the trees do not prune readily, causing the development of larger and older dead branches which are open to breakage and infection at an earlier age and also affecting the grade of lumber of the tree. In the pure stands, much suppression naturally results and fungous diseases are just as prevalent as in a mixed stand. Suppression in white pine is not always brought about by overcrowding or by adverse conditions on sites having little protection. Needle fungi may cause retardation by destroying the needles. *Lophodermium pinastri*, in its ascigerous stage and also in its pycnidial stage (*Leptostroma*), is a very common needle fungus throughout the white-pine type and is a factor to be considered in suppression. Mistletoes rarely attack white pine within its merchantable range and may be overlooked as a cause of suppression.

The three main wood-destroying fungi¹ for the areas studied are *Trametes pini*, *Polyporus schweinitzii*, and *Fomes annosus*. The first-named fungus, as the most important, is particularly active in western white pine throughout its merchantable range.

¹ Weir, J. R., and Hubert, E. E. Forest disease surveys. U. S. Dept. Agr. Bul. 658, 23 p., illus. 1918.

The sporophore (conk) of *Trametes pini* (ring-scale fungus) is brown, woody, usually stratified, and varies in shape and thickness. The usual form in the Northwest is a thin shell or scallop shaped structure, but it may become hoof shaped or resupinate, depending upon the position of the substratum or point of exit. Owing to the tendency of the mycelium to spread more rapidly vertically than horizontally in individual annual rings, a cross section of an infected tree shows the decay in the form known as ring-rot. The wood when first invaded by the mycelium of *Trametes pini* assumes a deeper reddish brown than when normal. It first becomes visibly characteristic with the appearance of pits in the wood lined with cellulose fibers. This is the well-known "honeycomb" stage and is the most characteristic stage of the rot. The decay, as indicated above, is not uniformly distributed in the heartwood, but the rot column may vary in location within the tree. This is also due to the fact that several separate infections may occur in the same tree, the diseased areas being separated by sound wood. As a butt rot, the general form of the rot column is conical, tapering at the upper limits. In the upper parts of the tree the rot column may be conical in both directions from the area of greater decay or from the point of first infection. The range of the vertical extent of the rot column in the tree may be from a few feet to the entire length of the tree when acting as a trunk rot and from 5 to 6 feet as a typical butt rot. External signs of the decay are the fruiting bodies, swellings of the trunk in a region of earlier infections, especially at branch whorls, due to the tendency of the tree to heal the old "punk knots," resin flow at swelled whorls or other points on the upper trunk, brownish punky material in old branch knots from which old sporophores have fallen, hollowness or punkiness indicated by soundings on the trunk, and the presence of various injuries.

Polyporus schweinitzii (velvet-top fungus) is usually not as conspicuous as the ring-scale fungus, owing to the fact that the sporophore rarely appears on the trunk but usually develops on the roots near by, and it may be partly obscured by the forest mold. It often appears a considerable distance away from the base of the tree. The fruiting body is in most cases stalked, the segments of the top incurving and colored a deep, rich brown. The margins when in a growing condition are of a lighter color. It sometimes appears from old wounds on the trunk in the form of brackets with or without a lateral stalk. The under side of the pileus is yellowish green, which turns reddish if injured. The fungus usually produces a uniform heart-rot of the butt of the tree. It enters the roots and decays the heartwood and may travel in this manner from root to root to neighboring trees. The decay produced is a light reddish

brown in early stages, but in its typical stage it becomes reddish brown, brittle and crumbly when dry, with a tendency to break into cubical blocks. The rot has sometimes the characteristic odor of turpentine. The rotted wood is carbonized by the action of the fungus and the cellulose is reduced.

The rot caused by *Trametes pini* is characterized by the delignification of the wood cells attacked. White patches of unreduced cellulose are left. The decay produced by *Polyporus schweinitzii* seldom advances beyond the first log and is usually not more than 5 to 6 feet up. The form of the rot column is conical from the base of the tree upward.

Fomes annosus (root Fomes) on the areas studied was least important. The sporophores of this fungus are generally found close under the surface attached to the roots and hidden by the forest mold. They are brown above, with a white spore surface and usually very irregular in outline. The early stages of decay range in color from lilac to reddish. In the typical stages the annual layers are separated by the more rapid decay of the summer wood. In a radial section white-pitted areas with black centers may be prominent. Finally the wood is converted into a spongy mass. The fungus causes a resin flow from the base of the tree and the roots. A fine felty mycelium is present under the bark in the early stages of decay. The rot column is uniformly circular in advanced stages and may extend from 6 to 8 feet into the first log.

FIELD STUDIES OF THE ROTS IN WESTERN WHITE PINE.

Field studies of the principal rots of a particular species of tree which aim to develop results of practical importance must necessarily be based on data taken from a large number of felled trees. It was decided that 100 trees of each age class for each of the two types of site would be a sufficiently large number to insure the best results. Seven age classes were determined upon as follows: 41 to 60, 61 to 80, 81 to 100, 101 to 120, 121 to 160, 161 to 200, and 201+ years. These are the age-class divisions used by the Forest Service in silvicultural practice in district 1. The two types of site, slope and bottom, were used, under each of which the seven age classes were ranged. Figuring 100 trees per age class and 7 age classes for each of the two types of site gives a total of 1,400 trees upon which accurate data on each tree are required in order to be fairly certain of the results.

Previous to the opening of the summer logging operations, all information relative to the age classes, sites, and locations of the various sale areas scheduled for cutting in the western white-pine

type in northern Idaho and western Montana during the field season of 1916 were secured. With this information plans were outlined and arrangements made to secure data on as many of the areas as were necessary in order to comply with the outline previously given. Thanks are due to the officers of the Cœur d'Alene National Forest for their helpful cooperation throughout the season.

In all, seven separate sale areas and one private cutting were covered in the study, and data were secured from each. The Lindberg, Honeysuckle, and Cathcart chances, or sale areas, are located within the drainage of the Little North Fork River. The Tent, Silver, and Boro Creeks sale areas are located in the drainage of the main Cœur d'Alene River, near Nelson, Idaho. The Bennett-Miner chance is located on the slopes adjacent to the North Fork of the Cœur d'Alene River, 20 miles above Prichard, Idaho. The private cutting is located near Priest River, Idaho, and is on the Humbird Lumber Company's land. All of the sale areas, with the exception of the private cutting on the Priest River, are located within the general drainage of the Cœur d'Alene River in the Cœur d'Alene National Forest of Idaho. All the areas studied are typical of the western white-pine type of forest.

Data were secured on the trees soon after the trees had been felled and before any of the logs had been removed by the skidding teams. In this manner it was possible to obtain data on a large number of trees each day. The entire tree was always available, and references to all the trees cut on that portion of the sale area included within the study were covered by the data. No selection of individual trees or groups of trees was practiced, the aim being to record accurate information on the general run of the stand according to age class and site. The sawing of the trees into standard log lengths of 8, 12, 14, and 16 feet by the logging crews offered splendid opportunities to obtain the rot dimensions and other data. The infected culled logs of merchantable size were opened up sufficiently to disclose the rotted area. The top portions of the tree beyond the merchantable limit were cut open by the data crew to determine the exact extent of the rot in cases where the rot ran into the top. Cooperation with the logging contractors and foremen aided greatly in keeping ahead of the skidding teams.

For data on the younger age classes not found on the sale areas, special permission was obtained to cut certain small areas of the younger trees on adjacent areas.

The trees on both the sale areas and the young age-class plats were numbered consecutively as they were measured and recorded, the number being placed on the stump, so that no duplication of trees occurred. Similar extensive and intensive data were obtained for

the white-pine study as were secured for the hemlock study,¹ and all available factors were taken into consideration in the final results. Forest descriptions were written for each sale area, and notes were made of the moisture and shade conditions existing on each.

The data obtained from a total of 1,417 trees, of which 135 were grand fir (*Abies grandis*), were first arranged according to site and age class. While in the field it was found that the number of trees needed in the two youngest age classes could be considerably reduced from the 100-tree standard. It was found that the trees on the 41 to 60 age class in both types of sites, slope and bottom, were uniformly free from visible decay. Owing to this condition and to the fact that young white pines of this age class are too small to be merchantable and should not be cut needlessly, it was decided to reduce the number of trees required. In the 61 to 80 age class it was found that the rots were in the beginning stages, and 60 trees per age class for each type of site were considered sufficient. In all the other age classes the number of trees was either above or but slightly below the 100 mark, except in the 121 to 160 age class on the slope sites, where the number was doubled in order to make a comparison between a similar age class and site for two widely separated sale areas, and in the 201+ age class, where it was impossible to find more than the recorded number of trees. There was, fortunately, one sale area which furnished a fairly large number of trees of the very old age class (201+).

Tables were prepared from the data collected, and these will be presented in the order of their consideration in the text. The volumes were figured by means of the Smalian formula. In these tables the word "Infected" as used at the head of certain columns is intended to cover all trees visibly infected. Early stages of infection not determinable by field observations and not measurable as recognized cull are not included.

RELATION BETWEEN ROT AND VARIOUS FACTORS.

AGE.

In Table I are found the data which show the relation between the rot volume and the age class of the stand. These data are separated under heads of "Bottom sites" (upper part of table) and "Slope sites" (lower part of table), and the data under each head are grouped according of the seven principal age classes.

Trunk-rot, indicated in the table by the initials T. R., represents mainly *Trametes pini*. Butt-rot, indicated by the initials B. R., represents *Trametes pini* when acting as a typical butt-rot, but in-

¹ Weir, J. R., and Hubert, E. E. A study of heart-rot in western hemlock. U. S. Dept. Agr. Bul. 722, 39 p., illus. 1918.

cludes *Polyporus schweinitzii* and *Fomes annosus* as well, and *Armillaria mellea* is sparingly represented.

In comparing the slope sites with the bottom sites it is well to keep in mind that the differences in these comparisons are made even more striking by the fact that the average age of the slope type of sites is greater by 14 years than that of the bottom type.

In Table I the average total volume per age class shows a steady increase for both types of site. The trunk-rot for both types also shows a definite increase from the 41 to 60 to the 201+ age class, the bottom sites indicating a greater percentage of rot than the slope sites. The bottom sites for the 61 to 80 age class show 0.8 cubic feet as the average volume of rot and 85 cubic feet for the 201+ age class, as compared to the slope sites, which have 0.055 cubic feet for the 61 to 80 age and 72 cubic feet for the 201+ class. The figures for the average rot volume for the butt rots on the two types of site vary considerably and do not show any consistent increase between the youngest and the oldest age classes. The 161 to 200 age class on the bottom sites runs extremely high, which may be due to the fact that the site from which these trees were taken was very favorable to butt-rot and supported a great deal of *Polyporus schweinitzii*. On the slope sites the average is less for the 161 to 200 age than for the class preceding it. This again must be accounted for by the local environmental differences present in the various areas upon which the trees included in this study were found growing. This is especially true of the 201+ age class on the bottom sites, in which no butt-rot is recorded and where the rot is almost entirely due to *Trametes pini* acting as a distinct trunk-rot.

The "T. R. + B. R." column gives figures for the combined rots, and in general indicates an increase in rot volume and in rot percentage with increased age.

Table I shows computations of the average annual increase in rot volume between the age classes per infected tree. These figures are intended to serve as an approximation of the rate of increase in rot volume during the life of the stand and are used later to determine the infection age.

A study of the relation between sound and infected trees reveals the fact that as the age increased, the percentage of infected trees increased at a quite rapid rate. The bottom sites show the more rapid increase of the two types of site. It is significant to note that the proportions of trees infected for the bottom and slope sites are almost identical, being 55 per cent and 55.3 per cent, respectively. If, in order to remove to a certain extent the source of error due to the larger percentage of trees of the older age class on the slope sites, the averages of the percentages for the different age classes are com-

pared, it is found that the bottom sites show a greater tendency toward favoring fungous development. The average percentage of infected trees for the bottom sites by this method is 52, and for the slope sites 47. On the bottom sites the rot percentage is 7.8, and on the slope sites 6.1. These figures indicate that although a slightly larger percentage of trees was infected (55.3) and although the trees were considerably older on an average on the slope sites, the bottom sites carry the larger rot percentage. Considering the various areas upon which data were taken as a unit, the total volume of rot was found to be 13,359 cubic feet and the total volume of the stand 193,432 cubic feet. This gives a rot percentage of 6.9, or 7.0 figured on a basis of 1,282 sound and infected trees, ranging from the 40 years' growth to the veterans of 450 and more years.

TABLE I.—*Relation of rots to age classes in western white pine on sites of the bottom and slope types.*

[Abbreviations: T. R.=trunk-rot; B. R.=butt-rot.]

Age classes.	Age computations (years).			Average volume (cubic feet).						Number of trees (basis).					
	Average.	Interval between classes.	Percentage of rot for stand.	Total.	Rot per infected tree.						Sound.	Infected.			
					T. R.	B. R.	T. R. + B. R.	Annual increase between age classes.				T. R.	B. R.	T. R. + B. R.	Percentage.
								T. R.	B. R.	T. R. + B. R.					
Bottom sites:															
41 to 60 years.....	52	.....	0	0.99	0	0	0	0	0	0	37	0	0	0	0
61 to 80 years.....	73	21	.16	30.7	.8	0	.8	.04	0	.04	58	4	0	4	6
81 to 100 years.....	88	15	.72	82.7	1.7	1.2	1.6	.06	.08	.055	73	38	5	43	37
101 to 120 years.....	113	25	1.67	150.9	4.2	2.4	4.0	.10	.05	.09	40	63	8	71	64
121 to 160 years.....	131	18	3.12	196.2	9.5	2.5	9.2	.29	.007	.29	43	83	3	86	67
161 to 200 years.....	180	49	15.67	203.0	19.0	281.3	33.6	.19	5.7	.50	4	68	4	72	94
201+ years.....	289	109	18.3	450.5	83.6	135.9	85.0	.59	0	.47	1	37	1	38	97
Total.....	125	.....	7.8	.....	18.1	61.6	21.6	.....	.....	.....	256	293	21	314	55
Slope sites:															
41 to 60 years.....	48	0	0	2.7	0	0	0	0	0	0	50	0	0	0	0
61 to 80 years.....	65	17	.06	4.6	.03	.14	.055	.0015	.008	.003	56	3	1	4	7
81 to 100 years.....	91	26	.37	11.2	.19	.16	.17	.006	.001	.0045	74	11	13	24	24
101 to 120 years.....	110	19	.45	57.9	.8	.295	.6	.03	.007	.025	59	30	11	41	41
121 to 160 years.....	137	27	2.34	178.9	5.7	6.0	5.7	.18	.21	.19	61	156	18	174	74
161 to 200 years.....	164	27	2.36	237.3	7.3	5.1	6.7	.06	.....	.04	17	61	21	82	83
201+ years.....	343	179	14.67	485.2	76.3	56.0	72.2	.38	.28	.36	1	55	14	69	98
Total.....	139	.....	6.1	.....	17.6	12.9	16.7	.....	.....	.....	318	316	78	394	55.3

SITE.

The western white pine is found in situations which supply sufficient moisture and shade to fill the requirements of the tree. Moisture plays an important part in its establishment and development, and this is emphasized by the fact that the western white pine attains its best growth in the regions where rainfall is plentiful.

In order to get a first-hand impression of the characteristics of western white pine from the point of view of the logger, questionnaires were sent to a large number of lumber and logging concerns operating in the Northwestern States. Out of the total answers received 18 were selected in which the replies to the questions were complete. Most of these answers were received from companies operating in the States of Oregon, Washington, Idaho, and Montana.

In respect to site, most of these answers state that the rot is greatest in trees occurring on flat, low, and poorly drained land, and that the best sites, where trees are freer from rot, are well-drained slopes or benches. Altitudes ranging from 1,500 to 7,500 feet are given as most favorable to healthy stands, and conversely the greatest proportion of rot is found in stands at altitudes below 1,500 feet.

In Table I it is seen that the proportion of rot on the bottom sites (7.8 per cent) is somewhat greater than on the slope sites (6.1 per cent). Apparently, this difference is directly due to the site and corroborates what has already been said in reference to environment favorable to fungous development. The above comparison of rot percentages for the two types of site is made more exclusive when the figures for the percentage of infected trees for each type are considered. The difference, presumably, would have been still greater if the proportion of the trees on sites of the slope type in certain of the older age classes had not been so much greater than for sites of the bottom type. In Table II a comparison is made between two sale areas in the same forest but separated by a considerable distance. The trees occurring on the slope sites only were used, and these were restricted to the age class of 121 to 160 years. A glance at Table II will show that the trees from the Honeysuckle sale area averaged 132 years and those of the Silver Creek sale area 142 years, a difference of 10 years.

TABLE II.—*Comparison of two sale areas of western white pine of the 121 to 160 age class growing on slope sites, showing the relation of rots to site.*

[T. R.=trunk-rot, B. R.=butt-rot.]

Sale area.	Average age (years).	Total volume (cubic feet).				Volume of rot (per cent).			Number of trees (basis).			
		Stand.	Rot.			T. R.	B. R.	T. R. + B. R.	Total.	Sound.	Infected.	
			T. R.	B. R.	T. R. + B. R.						T. R. + B. R.	Percentage.
Honeysuckle.	132	22,172	323.5	96.1	419.5	1.45	0.43	1.89	122	36	86	70.5
Silver Creek.	142	18,095	536.6	1.6	538.3	2.96	.01	2.97	106	24	82	77.3

This indicates a greater number of the older trees of the 121 to 160 age class on the Silver Creek sale area than on the Honeysuckle area. Continuing the inspection of the data in the table it is seen that the total volume of rot, the rot percentage, and the percentage of infected trees for the combined rots are all greater in the case of the Silver Creek area. The difference of 10 years between the average age for the two areas is apparently responsible for the difference in the rot activity just noted and gives further evidence that, the site being similar, the age of the stand affects the amount and percentage of rot as well as the number of trees infected. Eliminating the difference in the average ages between the two sale areas, the slope sites of the two areas should yield more nearly equal values for total volume of rot, rot percentage, and percentage of infected trees.

Another interesting point brought out in Table II is the variation in the amount of butt-rot for the two areas. Very little butt-rot is found upon the Silver Creek area (1.6 cubic feet) in comparison to that found on the Honeysuckle area (96.1 cubic feet).

In Table III comparisons are made between the rot percentages of trees occurring on the slope and bottom sites of the same sale areas. This method of comparison removes all possible variations which might be due to comparisons of plats occurring upon widely separated areas. In general, the figures show a higher rot percentage in trees occurring on the bottom sites than in those growing on the slopes.

On the Bennett-Miner sale area plat 1 was laid out upon the slopes and plat 2 on the bottoms. The bottom sites have a greater average by 38 years and also a greater rot percentage by 6 than the slope sites. In comparing the slope and bottom sites of the Silver Creek plat 1 area it is seen that the difference in average age is only 4 years, while the difference in rot percentage is approximately 5. Again, in comparing the Honeysuckle plat 1 with the Honeysuckle plat 4 area the difference in average age is 7 years and that of the rot percentage 4.5. The greatest difference in rot percentage is found in comparing the Humbird area with the Tent Creek area, between which are found differences of 39 years in average age and 7 per cent in the rot. This last comparison is not as dependable as the ones preceding, since the slope and bottom areas compared were taken from two widely separated sale areas. Similar criticism also applies to the comparison of the Honeysuckle plat 3 with the Silver Creek plat 2 area, which comparison indicates the possibility that the difference in average age may not be entirely responsible for the small rot percentage in the Honeysuckle plat 3 area. Comparing the same Honeysuckle plat 3 area with the Honeysuckle plat 1a area it is seen that a difference in rot percentage of 0.538 is more than balanced by a difference of 50 years, which latter is no doubt accountable for the larger rot percentage found on the slope sites.

Table I shows that for each type of site the rot percentage gradually increases from the youngest to the oldest age class, reaching 18 per cent in the bottom sites and 14.7 per cent on the slope sites. Comparing similar age classes of the two types of sites, the figures for rot percentage on the bottom sites run consistently higher than those of the slope sites.

TABLE III.—*Comparison of bottom and slope sites of different sale areas of western white pine, showing the relation of rots to site, independent of age classes.*

Sale area.	Bottom sites.				Sale area.	Slope sites.			
	Plat No.	Number of trees (basis).	Average age (years).	Rot (per cent).		Plat No.	Number of trees (basis).	Average age (years).	Rot (per cent).
Bennett-Miner.....	2	15	379.1	20.53	Bennett-Miner.....	1	71	340.6	14.62
Silver Creek.....	1	18	146.4	8.01	Silver Creek.....	1	100	142.2	2.98
Honeysuckle.....	3	70	72.0	.002	Silver Creek.....	2	149	79.0	.63
Do.....	1	347	111.0	5.23	Honeysuckle.....	1a	16	122.0	.54
Humbird.....		120	159.6	9.32	do.....	4	33	118.0	.70
					Tent Creek.....		241	120.7	2.19
Total.....		570			Total.....		712		

In comparing the average volume of rot for the two types of site in Table I a striking contrast is found between the butt-rot volumes. The average butt-rot volume on the bottom sites is found to greatly exceed the average volume for the slope sites, the average volume of trunk-rot is approximately equal, while the average volume of combined rots is shown to be somewhat larger on the bottom sites.

INFECTION AGE.

The average infection age, as defined in a previous work,¹ represents the average age of the youngest trees in the stand open to first infection by fungous enemies. It is the average age at which the stand is most liable to first infection and below which infection rarely occurs. Subsequent to this age infection is to be guarded against, as the chances of infection, up to a certain point, will continue to increase with the increase in age, number of injuries, etc.

In this bulletin the term *age of earliest infection* is used in place of "average infection age." It is believed the newer term will more accurately convey the meaning intended.

On the bottom sites, Table IV, the age of the earliest infection for the combined trunk and butt rots can be placed approximately in the 61 to 70 age class, since the first tree with visible decay is found in the 71 to 80 age class and is 73 years old. It must be remembered that actual infection is expected to take place some time before visible

¹Weir, J. R., and Hubert, E. E. A study of heart-rot in western hemlock. U. S. Dept. Agr. Bul. 722, 39 p., illus. 1918.

decay is present in the tree examined, and this fact would tend to place the age of earliest infection somewhat below the age of the tree at the time visible decay is noted.

TABLE IV.—*Relation of rot to age classes, with reference to the infection age of western white pine on sites of the bottom and slope types.*

Age class.	Bottom sites.					Slope sites.				
	Average age (years).	Number of trees (basis).			Average rot per infected tree (cubic feet).	Average age (years).	Number of trees (basis).			Average rot per infected tree (cubic feet).
		Total.	Infected.	Percentage infected.			Total.	Infected.	Percentage infected.	
41 to 50 years.....	48	16	0	0	0	45	33	0	0	0
51 to 60 years.....	56	21	0	0	0	56	17	0	0	0
61 to 70 years.....	66	21	0	0	0	63	48	2	4	.035
71 to 80 years.....	80	41	4	10	.79	74	12	2	17	.075
81 to 90 years.....	85	80	26	33	1.78	85	46	10	22	.213
91 to 100 years.....	94	36	17	47	1.38	95	52	13	25	.145

In Table IV the youngest trees found visibly infected on the slope site are in the 61 to 70 age class, and the age of the earliest infection would be found in the 51 to 60 age class. The youngest tree on the slope sites found to have visible decay is 61 years old. From these data it appears that the age of the earliest infection would be found between the ages of 50 and 60 years, and to be reasonably safe it may be placed at approximately 50 years.

Most of the answers received from the logging companies in reference to the question of the age at which western white pine is first infected give 50 years as the approximate age below which very little infection occurs.

It is apparent that factors other than that of site influence the percentage of infections as expressed by the figures in Table I. On the bottom site (Table I), the 61 to 80 age class, with an average age of 73 years, has only 6 per cent of the total trees infected, as compared to 7 per cent on sites of the slope type for a similar age class with an average age of 65 years. Density of stand and injuries such as fire scars could well be responsible for the increased infection of the trees on the slope sites. Farther along in the table it is found that for the bottom sites in the 81 to 100 age class, averaging 88 years, the percentage of infected trees is 37 as compared to 24 for the slope sites with a similar age class, averaging 91 years.

On both the slope and bottom types of site it is found that the 41 to 60 age class is entirely free from visible infection; that is, no measurable rot recognizable to the naked eye was found in these trees. This fact alone would indicate that an age of earliest infection placed at 50 years would be as nearly correct as the practical application of such an age demands. The site, apparently, is not the

determining factor as to the earliest age when infection may take place. The earliest visible infection for the groups of trees included in this study was found in a tree on the slope type of site, 61 years old. Table I shows that in the 61 to 80 age class the greater percentage of infected trees is found on the slope sites, while the bottom sites have the larger rot percentage.

INJURIES.

Since injuries play the principal rôle in the infection of living trees, it is important to consider them in relation to the various factors such as age and site and especially in relation to the rot volume. In Table V are given the data for bottom and slope sites, respectively, showing the relation of injuries to age class and to site, as well as indicating the percentage of infection traced to the various kinds of injury. The determination of the particular injury which was primarily responsible for the initial infection of the tree was most difficult in many cases, and no doubt a few of the individual decisions may be classed as doubtful. In the main such factors as the appearance of sporophores and the location of the largest ones, the region of greatest decay within the trunk, and the overwhelming occurrence of butt-rot in trees having large fire scars at the base give substantial evidence for the determination of most of the injuries responsible for infection.

The basis for the determination of the degree of injury rests on the following standard:

0 = No injuries.

x = 1 to 60 dead branches, no frost cracks, and very few miscellaneous injuries (less than 2).

xx = 61 to 120 dead branches, one frost crack, and a superficial blaze, logging scar, or other slight injury.

xxx = 121 to 180 dead branches, not more than 2 frost cracks, deep blazes, logging scars, or fire scars; slight lightning injury.

xxxx = 181 to 250 and more dead branches, more than 2 frost cracks, and heavy injuries (injured and broken top, severe lightning, and other injuries).

Dead branches were considered of prime importance in determining the degree of injury for individual trees. Fire scars proved an exception in a certain group of trees where the fire had caused injuries at the base, and these injuries were believed to be primarily responsible for the entrance of the fungus. These trees were of an age class bearing many dead branches. The younger trees had fewer dead branches than the older ones. Frost cracks were entirely absent in the younger age classes, so that no difficulty was experienced such as would arise in case a tree was found having only 60 dead branches and bearing 2 frost cracks. The older trees bore the few frost cracks found, and these trees had numerous dead branches.

In rating the averages for the various age classes x was given the valuation of 1, xx of 2, etc. In this manner averages such as 0.32 and 2.9 were computed (see Table V), indicating the average degree of injury.

TABLE V.—*Relation of injuries to age and to total stand of western white pine on sites of the bottom and slope types.*¹

Age class.	Infection traced to—								Total trees with in- juries to which infection was traced.	De- gree of in- jury.	Total num- ber of trees.
	Branch stubs.		Broken tops.		Frost cracks.		Fire scars and other injuries.				
	Num- ber.	Per cent. ²	Num- ber.	Per cent. ²	Num- ber.	Per cent. ²	Num- ber.	Per cent. ²	Num- ber.	Per cent. ³	
Bottom sites:											
41 to 60 years.....	0	0	0	0	0	0	0	0	0	0	0.32
61 to 80 years.....	3	75.0	0	0	0	0	1	25.0	4	6.5	1.74
81 to 100 years.....	23	53.5	0	0	0	0	20	46.5	43	37.1	2.09
101 to 120 years.....	50	70.4	0	0	0	0	21	29.6	71	64.0	2.6
121 to 160 years.....	68	79.1	0	0	1	1.2	17	19.7	86	66.7	2.9
161 to 200 years.....	65	90.3	0	0	2	2.8	5	6.9	72	94.7	2.6
201+ years.....	32	84.2	0	0	2	5.3	4	10.5	38	97.4	3.0
Total.....	241	76.7	0	0	5	1.6	68	21.7	314	55.0	2.4
Slope sites:											
41 to 60 years.....	0	0	0	0	0	0	0	0	0	0	0
61 to 80 years.....	3	75.0	0	0	0	0	1	25.0	4	6.66	.16
81 to 100 years.....	15	62.5	0	0	0	0	9	37.5	24	24.4	.7
101 to 120 years.....	26	63.4	0	0	0	0	15	36.6	41	41.0	1.41
121 to 160 years.....	137	78.7	0	0	1	.6	36	20.7	174	74.0	2.7
161 to 200 years.....	47	57.3	0	0	3	3.6	32	39.0	82	82.8	2.68
201+ years.....	67	97.1	0	0	0	0	2	2.9	69	98.6	3.77
*Total.....	295	74.8	0	0	4	1.0	95	24.1	394	55.3	1.9
											712

¹ Percentage of total trees (infected and sound) bearing injuries to total trees in stand = 70.

² Percentage based on total number of infected trees.

³ Percentage based on total number of trees.

Table V shows certain interesting results. On both types of site the infections traced to branch stubs bear the largest percentage over infections traced to other injuries, with 77 per cent for the bottom sites and 75 per cent for the slope sites. Broken tops as sources of original infection were not found, although a considerable number of broken-top trees were recorded and some of these trees gave evidence that a certain amount of infection took place through the exposed tip. In nearly every case it was found that infection in the lower part of the trunk had taken place some time previous to the breakage of the top, as indicated by the difference in the stage of development of the two rotted areas. On the bottom sites approximately 2 per cent of the infections were traced to frost cracks and 22 per cent to miscellaneous injuries, which latter included fire scars, blazes, windfall scars, etc. On the slope sites only 1 per cent of the infections were traced to frost cracks and 24 per cent to miscellaneous injuries. On the slope sites a larger percentage of infection traced to miscellaneous injuries is found than is recorded

for the bottom sites. This is due principally to the larger number of basal fire scars recorded for the trees on the slopes. On both types of site a steady increase of the total number of trees with injuries is recorded, ranging on the bottom sites from 0 in the 41 to 60 age class to 97 per cent in the 201+ class. On the slope sites the percentage ranges from 0 in the 41 to 60 age class to 99 per cent in the 201+ class. Comparing the entire stand of each type of site it is seen that the percentage of total trees infected is 55 on the bottom sites and 55.3 on the slope sites. A more correct comparison of the amount of injury found in the stands of each type of site is made by contrasting the percentages of total trees, both sound and infected, bearing injuries. For the bottom sites this percentage is 90 and for the slope sites 70, indicating that a larger number of trees on the bottom sites bore injuries. This difference may be partly due to the presence of a larger number of branch stubs on the trees of the bottom sites. These data clearly indicate the increasing danger of infection through injuries with the increase in age for both sites.

From a study of Table V it appears that frost cracks as sources of infection are more common in the older age classes and not present at all in the younger. The recorded field data show that frost cracks were more frequent in the older trees, which accounts for the preceding statement.

The degree of injury for the two types of site shows a fairly steady increase with increased age and a slight difference in degree of injury for the total stand of the two types of site. The bottom sites have but a few tenths greater degree of injury.

Table V shows that 10 to 30 per cent of the trees are without injuries. These trees are principally in the youngest age classes and bear no dead branches.

SPOROPHORES.

Most of the sporophores encountered in the western white-pine study were those of *Trametes pini*. Very few sporophores of *Polyporus schweinitzii* or of *Fomes annosus* were found attached to the trees. Most of the *Polyporus schweinitzii* fruiting bodies developed on the ground at the base or near the host, and the logging operations nearly always disturbed these from their original positions. A very few sporophores of *Polyporus schweinitzii* were found attached directly to the base of the tree. The data in Table VI, therefore, are principally from field notes on one fungus, *Trametes pini*. In this table it will be noted that the 41 to 60 age class is omitted, since no rot and therefore no sporophores were present on the trees of this class. On the bottom sites out of a total of 533 trees approximately 30 per cent were found bearing sporophores. On these sporophore-bearing trees a total of 604 sporophores were recorded, of which 561,

or practically 93 per cent (92.8), were alive and 43, or over 7 per cent (7.2), were dead, giving an average of 35 sporophores to every 10 trees for the live sporophores, 3 to every 10 trees for the dead sporophores, and an average of 38 sporophores both dead and alive for every 10 trees. An average of 11 sporophores both dead and alive for every 10 trees is found when all the trees of the six age classes are considered. Of the largest sporophores, which varied in size up to 6 by 6 by 8 inches, 92 per cent were found alive and 8 per cent dead. The average of the ages of the largest sporophores is approximately 15 years, and the average height on the trunk is 5.1 feet.

TABLE VI.—Summary of field notes relating to sporophores on western white pine on sites of the bottom and slope types.

Age class.	Num-ber of trees (basis).	Num-ber of trees bearing sporophores.	Number.			Largest.				Sporophores.										Number for each position on the tree.							
			Alive.	Dead.	Total.	Aver- age per tree.	Aver- age.	Condition.		Sizes. ^a	Relative position along trunk.	Aver- age height on tree.	North.	South.	East.	West.	North- east.	North- west.	South- east.	South- west.							
								Alive.	Dead.																		
Bottom sites:																											
61 to 80 years...	62	2	7	0	7	0.11	5.0	2	0	1 by 2 by 2.	Bottom.	Feet.	0	2	1	4	0	0	0	0	0						
81 to 100 years...	116	25	71	3	74	.63	5.3	24	1	4 by 3 by 5.	Middle...	1.8	13	10	11	23	1	5	3	4	5						
101 to 120 years...	111	46	145	11	156	1.4	13.3	42	4	3 by 5 by 5.	Top...	2.0	18	9	14	45	10	7	4	4	4						
121 to 160 years...	129	56	273	20	293	2.2	28.5	49	7	6 by 6 by 8.	do...	4.5	55	30	57	53	34	11	8	2	22						
161 to 200 years...	76	21	47	9	56	.74	19.6	20	1	4 by 6 by 8.	do...	6.4	0	13	13	15	0	0	2	10	10						
201+ years...	39	9	18	0	18	.46	23.0	9	0	2 by 4 by 6.	do...	32.5	0	0	8	8	0	0	0	0	0						
Total:	533	159	561	43	604	1.1	15.1	146	13	6 by 6 by 8.	Top...		86	64	104	148	45	23	17	41							
Percentage...		29.8	92.8	7.2				91.8	8.2				16.3	12.1	19.7	28.0	8.4	4.4	3.3		7.8						
Average b...			c 3.5	d 27	e 3.8		/15.1	All.				5.1				West.											
Slope sites:																											
61 to 80 years...	60	0	0	0	0	0																					
81 to 100 years...	98	0	0	0	0	0																					
101 to 120 years...	100	7	15	0	15	.15	8.6	7	0	3 by 3 by 3.	Bottom	2.4		1	10		1	1	1								
121 to 160 years...	235	105	405	25	430	1.83	11.24	101	4	6 by 4 by 7.	Middle...	3.3	93	45	61	76	23	26	21	57							
161 to 200 years...	99	23	57	5	62	.62	16.7	21	2	4 by 6 by 6.	do...	5.1	12	20	4	9	4	4	4	2							
201+ years...	70	9	18	6	24	.34	17.3	7	2	6 by 10 by 10.	do...	35.5				14	2	1	1	5							
Total:	662	144	495	36	531	.8	12.3	136	8	6 by 10 by 10	Middle...		105	66	75	99	30	32	27	64							
Percentage...		21.7	93.2	6.8				94.4	5.6				21.1	13.2	15.1	19.9	6.0	6.4	5.4		12.9						
Average b...			g 3.4	h 25	i 3.6		/12.3	All.				5.5															

^a The size of the smallest sporophore found wherever the presence of large sporophores is noted was 1 by 1 by 1 inch. ^b Per sporophore-bearing tree. ^c 35 to every 10 trees. ^d 3 to every 10 trees. ^e 38 to every 10 trees. ^f Average age of largest sporophores. ^g 34 to every 10 trees. ^h 25 to every 10 trees. ⁱ 36 to every 10 trees.

In classifying the sporophores according to the positions occupied on the trunk of the host it was found that the largest percentage of them (28 per cent) developed on the west side of the tree, with the smallest percentage (3.3) on the southeast side. Most of the largest ones were found near the upper end of the group on each tree.

On the slope sites, out of a total of 662 trees 22 per cent were found bearing sporophores. In this connection it must be remembered that a much higher percentage of the trees on the slope sites was in the 120 to 160 age class, which bore the maximum number of sporophores. The sporophore-bearing trees carried a total of 531 sporophores both dead and alive, of which 495, or over 93 per cent (93.2), were alive and 36, or nearly 7 per cent (6.8), were dead. These figures give an average for the total stand of 34 live sporophores to every 10 trees, 2.5 dead sporophores to every 10 trees, and 36 live and dead sporophores to every 10 trees. Considering all of the trees of the six age classes given and not limiting the figures to sporophore-bearing trees alone, an average of eight sporophores both dead and alive was found for every 10 trees. Of the largest sporophores, which varied in size from 1 by 1 by 1 to 6 by 10 by 10 inches, 94 per cent were found alive and 6 per cent dead. The average of the ages of the largest sporophores is recorded as approximately 12 years and the average height on the trunk was 5.5 feet. Most of the sporophores on this site were found grouped on the north side of the trunks, 21 per cent being on the north side and the smallest, or 5 per cent, on the southeast side. Most of the largest ones were found at about the middle of each group of sporophores.

In comparing the two types of site some interesting figures are disclosed. The bottom sites, to begin with, have a larger percentage of sporophore-bearing trees and a slightly larger average number both of living and of dead sporophores per sporophore-bearing tree. In the 81 to 100 age class the bottom sites have 22 per cent of the total trees bearing sporophores, while for the slope site there are none. In the 101 to 120 age class on the bottom sites 41 per cent of the total trees were found bearing sporophores, with only 7 per cent in the slope sites. In the 121 to 160 age class are found the maximum figures. In this age class for the bottom sites 43 per cent of the total trees bore sporophores and for the slope sites 45 per cent. The average of the ages of the largest sporophores is also greater on these sites. On the other hand, the slope sites have a greater percentage of the larger sporophores alive than the bottom sites. It is very interesting to find that the percentage of live and dead sporophores to the total number of sporophores is practically the same for both types of site. This would seem to indicate that site does not appreciably affect the vitality of the sporophore, although it apparently affects the number of sporophores produced.

On the bottom sites it is observed that sporophores are recorded for all the age classes, including that of 61 to 80 years. In the slope sites both the 61 to 80 and the 81 to 100 age classes have no sporophores recorded. The first sporophores appear in the 101 to 120 age class. They increase in number in the 121 to 160 age class and decline in the 161 to 200 and the 201+ age classes. The column indicating the average number of sporophores per tree indicates this very clearly. The column recording the number of sporophore-bearing trees shows a similar increase, reaching a maximum in the 121 to 160 age class, and a rapid decline is noted in the two succeeding age classes. These data indicate a maximum of sporophore production attained in the 121 to 160 age class and show the rapidly decreasing numbers of sporophores present on the trees of the two oldest age classes. Two factors are responsible for the decline—first, the fact that the fungus in the tree has reached and passed its maximum development and so produced fewer new sporophores, and second, the fact that in the old-age classes the old sporophores are observed to have died, become loosened from the trunk, and dropped off. The relation of rot percentage to sporophores is evident when compared on a basis of site. On the bottom sites the rot percentage is nearly 8 (7.8, Table I), and an average of 1.1 sporophore per tree or 11 sporophores to every 10 trees is recorded. In the slope site the rot percentage is over 6 (6.1, Table I), and the average number of sporophores per tree is 0.8 or 8 sporophores to every 10 trees. The bottom sites show a greater rot percentage and a greater average number of sporophores per tree.

Another interesting point brought out by the table is the fact that on both types of site the smallest groupings of sporophores were found on the southeast side of the trees.

DISCUSSION OF RESULTS.

From the foregoing data it appears that age is the important factor in determining the amount of rot to be expected in a western white-pine stand. This factor of age is significant in the application of proper silvicultural methods to the care and disposal of the timber. From the forester's point of view two things stand out in considering the stand in relation to rots. The one is the age of earliest infection of the stand, or the period when infection by fungi can first be expected. This is undoubtedly controlled by the formation of heartwood and the appearance of injuries susceptible to infection. This infection age is found to be approximately 50 years for western white pine, and it indicates the period when the young stand is in need of the utmost protection against infection by fungous spores. Infection takes place in this tree earlier than at 50 years in certain individuals,

and, of course, infection continues to take place in all stands after the 50-year period is reached, and no doubt at an increased rate.

The other consideration of importance to the forester is the period in the age of the stand at which the net increment of sound material passes its maximum. This period is more or less indefinite and difficult to express in actual age figures. It depends primarily upon what the forester considers the dividing line between a stand having sufficient sound material to pay a profit for logging and one having so much rot that logging would not be profitable or the profit a small one, all factors considered. From the viewpoint of annual increment the forester has determined that a rotation of 100 to 120 years for western white pine gives a maximum yield.¹ If this holds true, then it also appears that this will mean the cutting of the stand when the average rot percentage for the bottom sites is 1.7 and for the slope sites 0.5. Glancing at Table I it is seen that for both types of site an appreciable increase in the average annual increase in rot volume is recorded between the 101 to 120 and the 121 to 160 age classes.

In the sporophore summaries (Table VI) an apparent maximum point is reached in the 121 to 160 age class in respect to the number of sporophore-bearing trees and to the number of sporophores produced. The 101 to 120 age class would, therefore, represent the age class having, on the average, a stage of development of the rot below the maximum stage for sporophore production. These facts point to the 101 to 120 age class as a possible felling age from the pathological point of view, and it remains to discover whether an average rot percentage of 1.7 on the bottom sites and 0.5 per cent in the slope sites conforms to the most economical logging or whether a higher rot or cull percentage is possible without a sacrifice in the returns on the operation. The next higher age class (121 to 160) records a rot percentage of 3.1 for the bottom sites and 2.3 for the slope sites.

In the relation of age to injuries the data have shown that with increased age comes a greater degree of injury. This is evident for both types of site in all the age classes excepting the 161 to 200, which drops slightly below the preceding age class in degree of injury. It is so well understood that increased age brings cumulative risks of greater injury that a discussion seems unnecessary.

A steady increase in the number of trees with injuries to which infection was traced is noted with increase in age for both the bottom and slope types of site.

It is readily seen that age up to a certain limit has a definite relation to the sporophore production of a stand. If rot increases with

¹ Mason, D. T. Management of western white pine. *In Proc. Soc. Amer. Foresters*, v. 9, no. 1, p. 61. 1914.

age, then it follows that the production of sporophores will also increase as the decay develops to that stage where fruiting bodies are produced. It is also to be expected that when the period of maximum sporophore production is passed there will be a gradual decline in the numbers produced and also in the numbers retained upon the trunk. Fewer new sporophores are produced in the old-aged trees of the stand, and of the old sporophores already on the tree many die, become loosened from the trunk, and drop off. The data show for both types of site that there is an increase in the number of trees bearing sporophores and in the average number of sporophores per tree, from the 61 to 80 to the 121 to 160 age classes, inclusive, while a decrease is noted for the 161 to 200 and the 201 age classes. This indicates a maximum sporophore production in the 121 to 160 age class and a declining production for the age classes following.

Figures have been given which show that site plays an important part in the development of rot in a stand. The consensus of opinion among practical loggers is that low, flat, and poorly drained sites bear stands having the greatest amount of rot and that the sites where trees are freest from rot or where the rot percentage is small are well-drained slopes or benches. The comparison of slope and bottom sites in respect to rot percentage, both for age classes and for the total stand, indicates that a greater amount of rot is prevalent on the bottom sites. A comparison between trees taken from similar sites upon widely separated areas and having a difference in average age of 10 years shows a difference of 1 per cent in rot between these two areas. The percentage is greater on the area having the greater average age. The same indication is given by the figures for the percentage of infected trees. These data also furnish evidence of the influence of age upon the amount of rot to be found in a stand. Further comparisons of trees occurring on slope and bottom sites on the same sale areas also indicate that the trees on the bottom sites bear a greater percentage of rot than those on the slopes.

In respect to the influence of site upon degree of injury the data do not show conclusively that a greater degree of injury exists upon bottom sites. The bottom sites with 2.4 and the slope sites with 1.9 (Table V) leave too small a difference to attribute them to the influence of site. Apparently greater percentages of infections are traced to branch stubs on the bottom sites than on the slopes. This may be due to the formation of a larger number of dead branches on the bottom sites as a result of greater shade. Light more easily reaches the lower branches of trees growing on a slope than of trees growing on the bottom sites, providing the densities are about equal. This might be a possible explanation of the formation of a greater

number of dead branches on trees of the bottom sites. Site is apparently responsible for a greater percentage of sporophores developing on the trees of the bottom sites. An average for the bottom sites gives a distribution of 11 sporophores to every 10 trees, while the slope sites have 8 sporophores to every 10 trees. The proportion of live and dead sporophores to the total sporophores is about equal on each type of site, 93 per cent alive and 7 per cent dead. The proportion of live and dead sporophores to the total, in the case of the largest sporophores, shows a percentage approaching that already given, also showing very little variation in respect to site. A greater number of sporophore-bearing trees are found upon the bottom sites.

METHODS OF CONTROL.

From the study of the data presented, it appears that the control of diseases in western white pine under the present stage of forestry in the Northwestern States will be a difficult matter and subject to extensive rather than intensive methods. The high economic value of the tree and the large amount of loss due to rot are two important factors which make it imperative that steps be taken at least to check the diseases and that attempts be made to reduce the annual loss of sound material brought about by the spread of the casual organisms.

There are two methods of control which present themselves as practicable under the present methods of forest management. These two methods work hand in hand. The first method is primarily based upon the rotation of the stand or the felling age. It is evident from a study of the data presented that if the stand is cut before any sporophores are produced, or before they are produced in any great numbers, the spread of the diseases will be effectively checked. The data show that a certain age class represents the period in the stand which develops a maximum of sporophores. This period in western white pine is represented by the 121 to 160 age class. This age class has 43 per cent of the total trees bearing sporophores for the bottom sites and 45 per cent for the slope sites. Both the next lower and the next higher age classes have smaller percentages for the two types of site than the 121 to 160 age class. If the felling age of western white pine is kept within the 101 to 120 age class there is every reason to believe that the infected trees will be cut down before they reach the age of maximum sporophore production. Most of them will no doubt be cut down before any fruiting bodies whatever appear. This is the most desirable result and is particularly true for the slope sites.

The second method is fundamentally concerned in the strict application of proper pathological marking rules and the consequent re-

removal of all infected slash on the sale areas. The marking rules should provide definite instructions to fit each distinct sale area and should include the consideration of the classification of stands in the western white-pine type and the methods of cutting employed on each. The pathological marking rules should specify the cutting of all diseased trees on a sale area where selection cutting is employed and the retention on clean-cut areas of seed trees free from all root, butt, and trunk rots, as well as from rust and mistletoe. These two recommendations will insure a healthier second growth in the case of selection or improvement cuttings, and in the case of clean-cut areas will insure the reserved seed trees against windfall and wind-break due to fungous activity.¹ In the case of the clean-cut area the retention of sound seed trees will also prevent distribution of diseases by these trees. If seed trees other than western white pine are reserved, the selection of sound trees will prevent infection of young growth by the rust² and mistletoe³ diseases which are peculiar to certain tree species, such as Engelmann spruce and western larch, found in stands of the western white-pine type. The removal of all infected slash left on a sale area after logging is an important part of the successful control of fungous diseases. In order to prevent the spread of the diseases which have caused rot in the trees of the stand all infected slash liable to develop sporophores should be disposed of in such a manner as to check the development of the fungus and thus prevent subsequent sporophore production, or it should be destroyed outright in some manner consistent with economic requirements.

SUMMARY.

Data obtained in a study of the rots of western white pine show the following conclusions as presented in this bulletin:

The three main wood-destroying fungi in the order of their importance are *Trametes pini*, *Polyporus schweinitzii*, and *Fomes annosus*. Most of the rot found in the tree is traceable to *T. pini*.

Trametes pini attacks all portions of the trunk, acting in some cases as a typical butt-rot. *Polyporus schweinitzii* is found to produce a typical butt-rot, and *Fomes annosus* is chiefly confined to the roots and butt of the tree.

¹ Hubert, E. E. Fungi as contributory causes of windfall in the Northwest. *In Jour. Forestry*, v. 16, no. 6, pp. 696-714. 1918. Bibliography, pp. 713-714.

² Weir, J. R., and Hubert, E. E. Notes on forest-tree rusts. *In Phytopathology*, v. 8, no. 3, pp. 114-118. 1918.

——— Notes on the overwintering of forest-tree rusts. *In Phytopathology*, v. 8, no. 2, pp. 55-59. 1918.

³ Weir, J. R. Larch mistletoe: Some economic considerations of its injurious effects. *U. S. Dept. Agr. Bul.* 317, 25 p. 1916.

——— Some suggestions on the control of mistletoe in the national forests of the Northwest. *In Forestry Quart.*, v. 14, no. 4, pp. 567-577. 1916.

It is found that an average rot percentage of 7 represents the proportion of sound wood rotted by these agencies in the stands of timber classified under the western white-pine type. This represents a loss of \$7,201,250, or 1,658 million feet B. M., in the forests of British Columbia, Oregon, Washington, Idaho, and Montana.

The data indicate that the factor of age is prominent in determining the amount and stage of decay in a stand. The age of earliest infection was found to be approximately 50 years for the trees in general for the Cœur d'Alene region of Idaho.

Site is found to have a bearing upon the rot in the stand. The bottom site, in general, is found to be more favorable to the development of fungous diseases. Site, apparently, has no great effect upon the percentage of trees infected, both sites showing approximately the same percentage. A larger percentage of the slope trees were in the heavier infected age classes. This was not the case for the bottom sites, and therefore a direct comparison of the total percentage of trees infected gives figures which are higher for the slope sites than would otherwise be true. In general, a greater rot percentage, a greater percentage of infected trees, a greater amount of butt-rot, a greater degree of injury, and a larger average number of sporophores per tree are recorded for the bottom sites than for the slopes. This indicates that the bottom sites are more favorable to the development of fungous diseases.

With increased age up to a certain point comes an increase in the number of sporophore-bearing trees and an increase in the degree of injury.

The maximum production of sporophores is found to occur in the 121 to 160 age class. The 101 to 120 age class presents, in so far as the rot data show, favorable figures upon which to determine a pathological felling age.

The high economic value of the tree coupled with the large amount of loss annually sustained through heart-rotting fungi makes it highly necessary to attempt control methods.

The loss due to rots may be reduced by the application of control methods aiming to prevent the spread of the organisms causing decay.

Proper pathological marking rules and practical methods for the disposal of infected slash on sale areas are recommended as methods of control.

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WM. A. TAYLOR, Chief



Washington, D. C.

PROFESSIONAL PAPER

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THE DRY-ROT OF INCENSE CEDAR.

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IMPORTANCE OF INCENSE CEDAR.

Incense cedar (*Libocedrus decurrens*) is of considerable economic importance on the Pacific coast. The available supply of this species, which never occurs alone but always in mixture, chiefly with yellow pine, Jeffrey pine, sugar pine, Douglas fir, and white fir, averaging about 8 per cent of the stand, although often forming as high as 30 to 50 per cent, is estimated at 11 billion feet, 10 billion of which occurs in California (17, pp. 9-10).¹ That the wood is very valuable for special purposes on account of certain qualities has been clearly pointed out by Mitchell (17, pp. 2-9) recently and was mentioned by Von Schrenk (26, p. 69) 20 years ago. However, in spite of the well-known value of the wood, only about 30 million feet is cut annually in California. The stumpage rate is low and the price for the finished product often little more than pays the cost of logging and manufacture, according to Mitchell (17, p. 6).

The reason for this is obvious. The heartwood of incense cedar is commonly rendered totally worthless by the so-called dry-rot caused by *Polyporus amarus*. An idea of the quantity of timber rendered unmerchantable by this dry-rot may be obtained from Mitchell's statement (17, p. 3) that so common is this defect that it is the usual practice to cut estimates of this species from 30 to 50 per cent on ac-

¹ The serial numbers in parentheses refer to "Literature cited" at the end of the bulletin.

count of it. This leads to a distinct prejudice against the species on the part of both the lumberman and the forester. The lumberman is naturally averse to handling a large quantity of practically worthless material for which there is little or no market in order to secure a small amount of valuable material, when the profit on the more valuable product is not sufficient to carry adequately the entire product. The forester sees a species of very little value, as attested by the low stumpage rate, occupying space which might be given over to surrounding species on which a much higher stumpage rate could be realized.

This prejudice, which has resulted in the classification of incense cedar as an "inferior" species, is not based on any inherent quality of the tree itself, for sound cedar wood, as has already been stated, is quite valuable, finding a ready market; and the tree, on account of its relatively high tolerance of shade, particularly during its earlier life, is a valuable component of the mixed stand in which it occurs.

Incense cedar is a thrifty, aggressive species, quite tolerant of shade, and has a definite, permanent place in the forests of the Pacific coast. Its aggressiveness makes it almost an impossibility to eradicate the species entirely, and such an attempt would be highly inadvisable and might result in unforeseen disastrous consequences resulting from an artificial change in the composition of the stand. Greeley (6, p. 112) and Meinecke (16, pp. 21-22) have specifically advised against this. The lumberman, logging in types with incense cedar represented, faces the necessity of handling a large quantity of almost worthless timber, which if sound would be of high value.

Since incense cedar probably can not be eliminated from the stand, the problem presents itself of the proper treatment of an inferior species which in time will undoubtedly become quite valuable. Foresters and lumbermen are showing more and more interest in the question, fully realizing that this species will always have to be reckoned with. We must have exact, far-reaching studies not only to handle properly and utilize the cedar at present, but to lay the foundations for a rational system of silvicultural management for the future. Production is inevitable; proper treatment must be evolved. Consequently, the study on which this paper is based was undertaken in an attempt to throw light on certain of the phases involved.

TOTAL-LOSS FACTORS.

Throughout American forestry literature dealing with regulation and management are found statements in regard to individual components of mixed stands to the effect that "in virgin forests increment equals decay," or sometimes "deterioration" is used in place of "decay." Chapman (2, p. 317) and Meinecke (16, p. 3-4) have shown this generalization to be of absolutely no value, since the as-

sumption is based on the factors of increment and decay, of which almost nothing is known. When deterioration is used in place of decay, it is an impossibility to reach a conclusion as to just what factors of loss are included in the term.

The term "total loss" has been introduced by Meinecke (16, p. 4-5) to cover all factors which lead to any reduction of increment or actual volume in a stand, and he makes a strong plea for exact studies of all components of the total-loss factor for individual species before any effort is made to determine this for the mixed stand.

To determine the components of the total-loss factor for any given species is merely a matter of simple observation, but to gauge accurately their relative importance is not easy, calling for careful comprehensive work.

In the case of incense cedar the numerical dropping out of individual trees, the mechanical injuries caused by fire, frost, lightning, the breaking of branches, and other causes, a mistletoe, and several fungi play a more or less important part in the total-loss factor. These components may be divided into two broad classes, those reducing the future capital of timber (lessening the increment) and those reducing the present capital of timber (destroying actual merchantable material). It is impossible to draw a sharp line between these two classes, since some components find a place in both.

The unavoidable yearly dropping out of certain trees, varying in size from seedlings to veterans, affects both the increment and merchantable material in a stand. Mechanical injuries, while primarily causing a loss in the merchantable timber, to some extent interfere with the normal growth of the tree, thus reducing the increment.

A mistletoe (*Phoradendron juniperinum libocedri*), the incense-cedar rust (*Gymnosporangium blasdaleanum*) (15, p. 35-37; 11), a leaf-inhabiting fungus (*Stigmatea sequoiae*) (3, p. 87; 4, p. 314), and the black cobweb fungus (*Herpotrichia nigra*) all primarily cause a loss in the future capital of timber by reducing the annual increment of infected trees. The amount of this loss is exceedingly difficult to gauge accurately, but it is so small in relation to the damage caused by the agencies reducing the present capital of timber that the above-mentioned organisms are given no consideration in this paper except incidental mention. Under certain conditions, the mistletoe is responsible for a slight reduction in the merchantable contents of the host tree by causing spindle to barrel shaped swellings on the boles of mature and overmature trees (14, p. 37). The wood of these swellings is rendered valueless for lumber, owing to the presence of the mistletoe "sinkers," or roots, either living or dead. Swellings are rarely, if ever, found on the boles of younger trees.

Most important of all, however, is the loss of the present capital of timber through decay. The organisms causing decay in incense cedar are the pouch fungus (*Polyporus volvatus*), *Polystictus abietinus*, *Polystictus versicolor*, *Lenzites sepiaria*, the red-belt Fomes (*Fomes pinicola*), some unknown fungi, and the incense-cedar dry-rot fungus (*Polyporus amarus*). The first five listed have never been found attacking living incense cedars. There are several forms of decay of trifling importance in living trees, the causes of which have not been determined. *Polyporus schweinitzii* has been found in one case.

Standing out above all the other components of the total-loss factor is *Polyporus amarus*, causing dry-rot in the heartwood of the tree. Since the first utilization of incense cedar, the great destruction wrought by this fungus has been a matter of extreme concern to lumbermen and foresters, as is shown by the constant references to the decay found throughout the literature wherever incense cedar is mentioned.

The importance of dry-rot can not be overestimated, and it is on this point, together with the related mechanical injuries, that a study of the total-loss factor must be concentrated; the other considerations play a distinctly secondary rôle.

METHOD OF COLLECTING DATA.

SELECTION OF AREAS.

The first step in carrying on a study of the total-loss factors in any given species is the selection of proper areas for work. The areas selected, if the results are to serve for any but strictly local application, must be representative of the larger unit or region of which they form a part. It is self-evident then that areas located in the altitudinal or horizontal extremes of the range of the species under investigation must be avoided. The results of a study on such areas, while scientifically interesting, would be absolutely without practical value, since they would only answer for a limited unit on which the stand is abnormal and would fail to answer any questions in regard to the major and more valuable portion of the range of the species.

All indications tend to show that there is a considerable variation in the growth and development of incense cedar in different parts of its range. This has already been hinted at by Mitchell (17, p. 9, 13, 23, 24). The writer distinguishes three distinct ranges based on the development of the tree, and these are termed, for convenience, the optimum, intermediate, and extreme ranges.

The best development is found in the southern Sierras, particularly on the Sierra, Sequoia, and Stanislaus National Forests, and the southern portion of the Eldorado National Forest, where the species is relatively rapid growing and thrifty.

In the intermediate range, comprising the northern Sierras and the Coast Ranges, slower growth is the rule, and in the mixed stand where the cedar always occurs it plays a distinctly secondary part and might almost be classed as an understory tree.

The poorest development is found in the extreme range, which includes stands at the horizontal and altitudinal extremes of the distribution of the species. In such situations the trees are short, scrubby, and relatively of little value.

With the above facts in mind, it was considered essential to choose areas representative of the intermediate and optimum range; the extreme range could be neglected, since it is of no practical importance.

In the uneven-aged stands care had to be observed to select areas on which all age classes were represented, since if there is a relation between any of the total-loss factors and age of the tree, this would fail to appear if even-aged or nearly even-aged trees alone were considered.

Observation and a preliminary study by Meinecke¹ showed conclusively that the total-loss factor of supreme importance in the case of incense cedar is dry-rot caused by *Polyporus amarus*. Above all, then, it was essential to select stands in which dry-rot was common, using discretion not to make the selections where loss from dry-rot was far above or below normal. Other total-loss factors, particularly mechanical injuries, could not be disregarded and were carefully considered.

With a knowledge of the habits and condition of incense cedar throughout its range, several possible areas were tentatively chosen, a careful examination made in each case, and then the most suitable stands were decided upon.

DESCRIPTION OF AREAS.

The area selected to represent the intermediate range is at Sloat, Calif., within the boundaries of the Plumas National Forest, in the northern Sierra Nevada Mountains. In general, the region is one of heavy snowfall, with moderate winter temperatures and a long, dry, warm summer season. Lightning storms are not very frequent.

The tract has a relative altitude of 4,300 to 4,700 feet. The fairly deep soil is a decomposed lava, normally dry and loose.

The virgin uneven-aged stand, with a strong representation of mature and badly overmature trees of all species, is principally composed of western yellow pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*), and Douglas fir (*Pseudotsuga taxifolia*). Where

¹ The writer wishes to acknowledge his indebtedness to Dr. E. P. Meinecke, who first inaugurated a study of incense cedar in 1912, the data obtained being included in this paper, for advice and direction throughout the course of all the later work. The essential methods followed in this study are outlined by him in United States Department of Agriculture Bulletin 275 (16).

Douglas fir predominates, the two pines take second place, and vice versa. Third in order comes incense cedar, while sugar pine (*Pinus lambertiana*) and white fir (*Abies concolor*) are but lightly represented.

In the more dense stand on the lower slopes and in the draws incense cedar forms a distinct understory, overtopped by all the other species; it is in such localities that the cedar shows every indication of slow growth and strong suppression. On the higher slopes and along the ridges, where the stand is more open, the cedar in individual cases often assumes a better position in the stand, and all the trees of this species, with few exceptions, appear to be more thrifty and to have made a more rapid growth. Badly suppressed trees are rare.

The three areas selected to represent the optimum range are on the Stanislaus National Forest in the southern Sierra Nevada Mountains. One of these is at Strawberry, at an altitude of 5,300 to 5,600 feet; a second at Cow Creek, about 5 miles north and east of the first and at about the same elevation; and the third at Crockers Station, about 30 miles to the south and a little east of the Strawberry area and at an altitude of about 4,500 feet. Since the areas are so nearly alike, a composite description will suffice.

The soil is a rather deep, loose, decomposed granite, with many large granite boulders. It is normally somewhat dry.

The virgin uneven-aged overmature stand is rather open and is composed of sugar pine, western yellow pine, Jeffrey pine, white fir, incense cedar, and Douglas fir. Normally the pines predominate, with white fir or incense cedar next in order, Douglas fir being found sparingly only on the Crocker area. Incense cedar is represented by trees of all ages, and on the whole appears very thrifty. There are many individuals of large size, comparatively young. The cedar here is far from forming such a distinct understory as on the Sloat area, so the stand has made a much more rapid growth.

NOTES ON INDIVIDUAL TREES.

After the general notes were completed on an area, work was commenced on individual trees. Trees of all ages and conditions must be cut for a study of this kind, the primary purpose being to determine the age of the stand at which dry-rot becomes extensive. Observations on logging operations and the results of Meinecke's preliminary study had shown that trees between 100 and 240 years old would yield the essential data on this point, and it was within these age limits that the investigation was concentrated, but the lower and higher ages were not neglected by any means. This resulted in clear cutting within the ages mentioned, except that those trees in which it was plainly apparent an accurate age count could not be made were left standing, while only a portion of the trees in the stand above and below these ages were cut. Thus, since a given

tract was not clear cut, the representation of age, diameter breast high, and height classes obtained from the study must not be assumed as an exact expression of the actual conditions.

Each tree was cut as closely as possible to a stump height of 18 inches, then limbed and bucked. The first or butt log was made 7 feet long and the others 14 feet long, the number of cuts depending, of course, on the length of the tree. The last cut was always made well in the top near the upper limit of the heartwood. The reason for bucking in 7 and 14 foot lengths was purely a practical one; any sound heartwood could then be utilized for 7-foot posts. The age count at stump height was taken as the age of the tree instead of adding a few years corresponding to the height of the stump, since the aim is to have all figures taken directly comparable. In this case with a minute constant variation no error can be introduced. Trees with wounds which destroy the center at stump height were avoided when possible, since in such cases an accurate age count could not be obtained; hence, trees of this kind are valueless for all further calculations in which the exact age is a factor. The sap width was obtained from an average of six or eight measurements. Three radii were measured to secure the average diameter. Separate measurements were made for the area covered by decay. The dates of occurrence and closure, when healed, were determined for all wounds present. Each log was split at least once in order to reveal completely all decay and internal wounds. Great care had to be observed in splitting the logs in order to be certain not to miss any decay, since the dry-rot occurs in pockets which may be separated in a linear direction by several feet of sound wood. This habit of "jumping" also made it exceedingly difficult to trace the entrance of the decay in certain cases where the decay might be several feet removed from any possible point of entrance. It often became necessary to split log after log into many small pieces.

In all, 1,075 trees were analyzed, 509 at Sloat, 266 at Strawberry, 100 at Cow Creek, and 200 at Crockers Station.

In all future references in this paper, for the sake of convenience the term "intermediate area" will be used to designate the area at Sloat, since it represents conditions in the intermediate range, and the term "optimum area" to designate the combined areas at Strawberry, Cow Creek, and Crockers Station, since they represent conditions in the optimum range. The results of the field work follow.

SECONDARY ROTS.

Under this heading are grouped all decays the causes of which are unknown. Such decays are of various types and are almost invariably found immediately adjacent to open or healed-over wounds, particularly fire scars. Instances were encountered where

the decays were so badly eaten out by insects as to preclude any description of the rot. By reason of this, some light infections of *Polyporus amarus* may have been included under secondary rots, but such cases have undoubtedly been very rare.

Of the 59 infections of secondary rots examined, only 9 resulted in culls of any importance, the highest percentage of unmerchantable timber in relation to the total volume of the tree being 19.5 per cent. In all the remaining 50 trees the infections were negligible. These figures show secondary rots to be of only trivial importance in reducing the merchantable volume; hence, such decays are not further considered in this paper.

THE DRY-ROT.

The dry-rot of incense cedar, termed by eastern workers "peckiness" or "pin-rot," caused by the fungus *Polyporus amarus* Hedge., was first described and figured by Harkness (7) but no cause was given. Next Von Schrenk (26, 67-77, pl. 2, 4, 5) described and figured the disease without stating the cause, and later (28) he mentions *Polyporus libocedris*, but without giving a description of type specimens. Hedgcock (10) first definitely assigned the cause of the dry-rot to *Polyporus amarus* sp. nov. and described the fungus. Later Meinecke (15, p. 35-37) presented a brief description of the sporophore, accompanied by a photograph of a typical fully developed bell-shaped specimen, with the upper surface partially destroyed by insects. Murrill (24, p. 25) places the fungus in the genus *Fomes*.

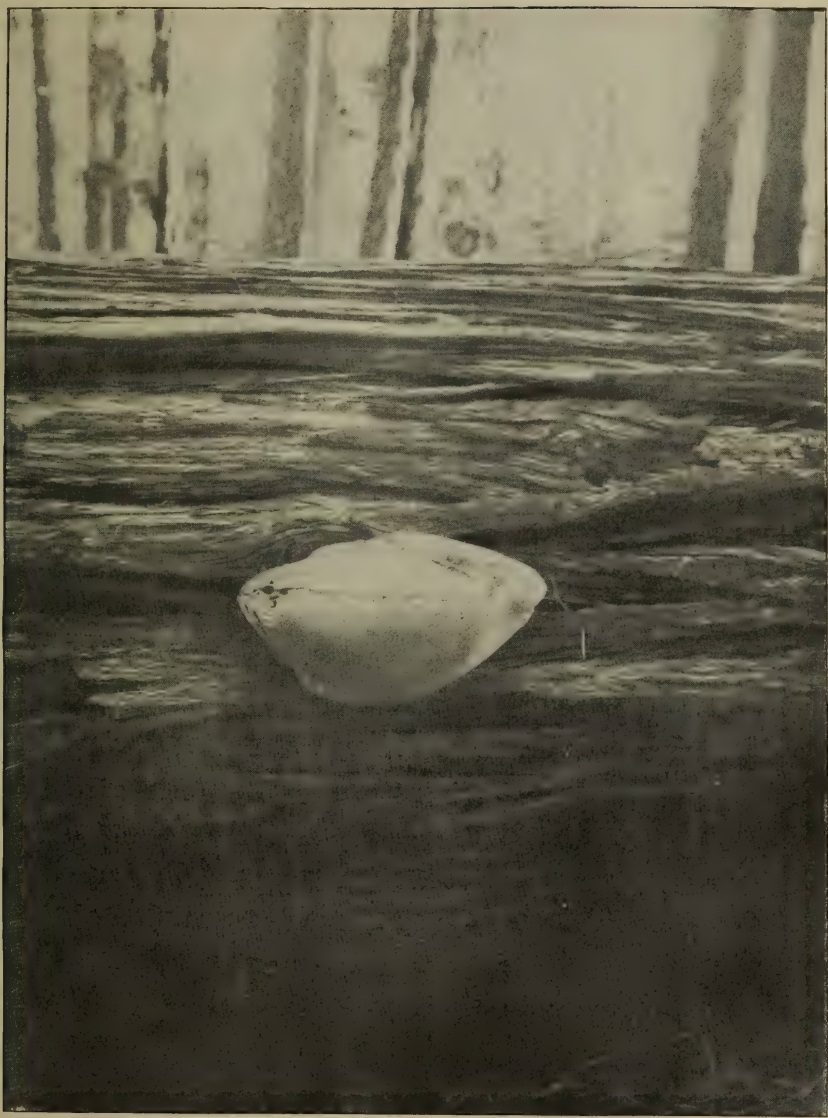
Harkness and Moore, Mayr, and Sargent have attributed the cause of the dry-rot to *Daedalea vorax* Hke., but Von Schrenk (26, p. 67-68) has shown this to be an error. Farlow and Seymour (5, p. 169) and Bryant (1, p. 15) have made the same mistake.

The dry-rot is very widely distributed. It has been found at elevations varying from 650 to 6,480 feet as far north as Oakridge, Lane County, Oreg., west to the west of China Flat, Humboldt County, Calif., east to Shaver, Fresno County, Calif., and south to the north and east of Mentone, San Bernardino County, Calif. In fact, from all indications and hearsay evidence it is quite reasonable to presume that dry-rot is more or less prevalent in incense cedar throughout the range of the host (30, p. 150-152).

THE SPOROPHORE.

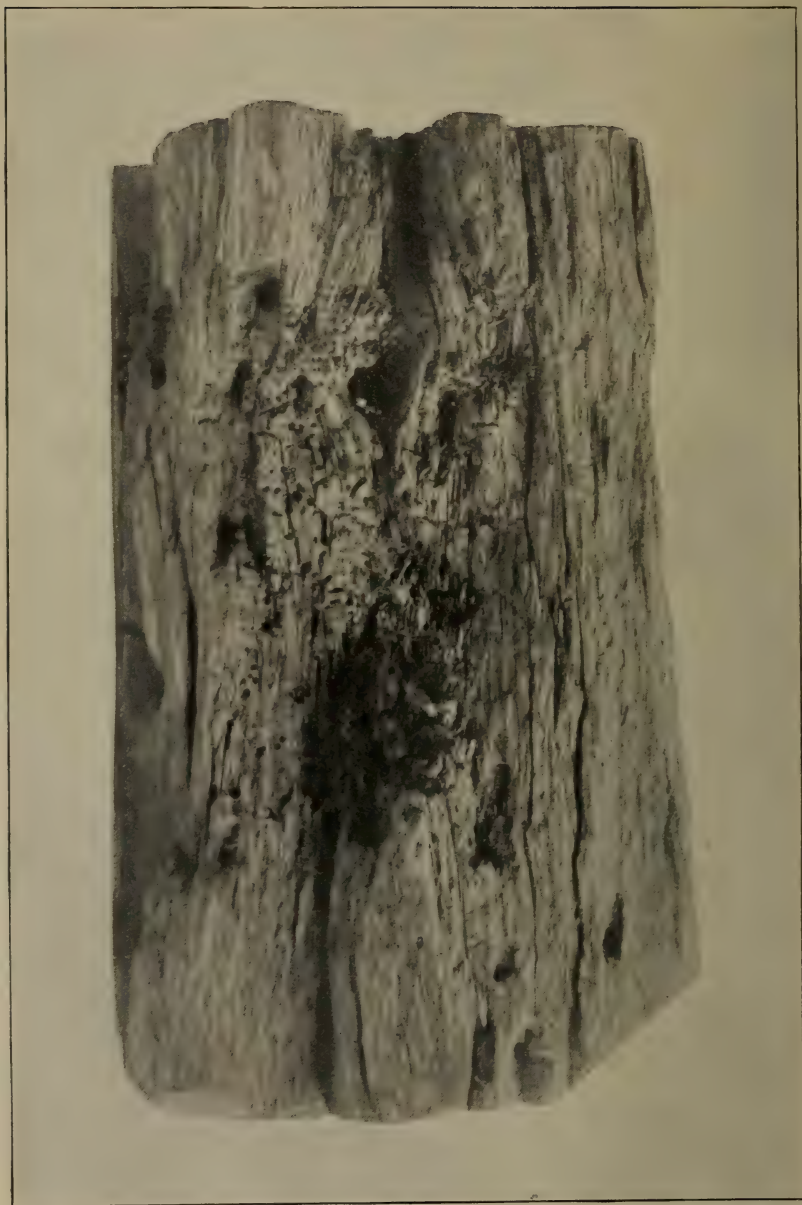
Since Hedgcock's description was published, so many sporophores have been collected that the original description may be supplemented by the following, which is based on the examination of 25 sporophores, both fresh and old:

Polyporus amarus.—Pileus soft and mushy when young, then rather tough and cheesy, finally becoming hard and chalky when old, ungulate, bell shaped or occa-



A FRESH SPOROPHORE OF POLYPORUS AMARUS ON A DOWN TREE.

Photographed by Gravatt.



AN OLD SHOT-HOLE CUP. THE ORIGINAL SPOROPHORE ISSUED FROM THE KNOT HOLE AT THE TOP.

Photographed by Meinecke.

sionally subapplanate, often spuriously stipitate from knot holes, 4 to 15 by 5 to 22 by 5 to 20 cm., commonly 7 to 10 by 11 to 13 by 8 to 13 cm., occasionally abortive without hymenial layer, then assuming irregular shapes; surface pubescent when young, rimose and chalky when old, at first buff, then tan, and often blotched with brown when attacked by insects; margin obtuse, frequently having an outer band of darker brown, often slightly furrowed; context homogeneous,¹ lemon-yellow, later buff to tan, usually darker near the surface when old, slightly bitter to the taste, 4 to 14 cm. thick, commonly 9 to 11 cm., usually friable when dry but occasionally becoming partially horny, hard; tubes not stratified, lemon-yellow within, cylindric 0.2 to 3 cm. in length, shorter next the margin, mouths circular or slightly irregular, 1 to 3 to a millimeter, lemon or sulphur yellow during growth, turning brown when bruised or old, becoming lacerate; under surface of the hymenial layer sometimes exuding clear yellow drops of liquid, sweetish to taste; spores hyaline or slightly tinged with yellowish brown, smooth, ovoid (200) range 3 to 6.5 μ by 4.5 to 9 μ ; standard size 3.5 to 4.5 μ by 6.5 to 7 μ , nucleated; cystidia none.

The following table presents detailed measurements of 24 sporophores of *Polyporus amarus*:

TABLE I.—Sporophore measurements of the incense-cedar dry-rot fungus.

cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
3.8 by	4.8 by	8.3	8.0 by	13.0 by	13.0	9.5 by	17.0 by	13.3	
4.2 by	5.5 by	5.5	9.0 by	11.5 by	9.9	9.8 by	13.2 by	13.0	
6.0 by	7.3 by	8.6	9.0 by	10.0 by	10.0	10.3 by	14.9 by	14.8	
6.8 by	11.2 by	12.3	9.0 by	10.5 by	11.0	11.4 by	20.7 by	19.8	
7.5 by	11.4 by	9.0	9.0 by	13.3 by	12.0	12.0 by	16.4 by	10.8	
7.5 by	17.0 by	8.1	9.1 by	10.7 by	8.5	12.1 by	21.2 by	12.5	
7.6 by	11.4 by	9.5	9.1 by	12.4 by	8.9	14.5 by	22.0 by	13.0	
8.0 by	12.5 by	10.0	9.5 by	14.7 by	11.0	14.8 by	12.7 by	16.5	

The sporophores, which last for one season only even at best, are not at all common, a statement which is supported by the number of years the dry-rot was known before the cause was definitely determined. During certain years sporophores seem to be very rare. They most commonly occur in the summer, and especially in the fall, but occasionally are found at other seasons. Observations record two fresh ones in March in a rather mild climate at an altitude of about 3,000 feet in the Sierra Nevada. Another was found in a different locality in June. No sporophores have been found developing later than October, but occasional fresh ones may be carried over from a previous fall into the winter in a frozen condition. They are then destroyed in the spring.

Typically the sporophores are produced on living trees but are, on occasions, found on dead fallen trees. (Pl. I.) Seven such cases have been observed during the past five years. In five of these it was possible to determine the time which elapsed between the felling of the tree and the appearance of the sporophore. Three of the sporophores were produced 3 years, one 4 years, and one 27 years after the trees had been cut. As to how long the mycelium may

¹ The substance of the sporophore not including the outer layers.

persist in a dead fallen tree it is impossible to state, but the last figure given indicates a rather extended period in some cases. These cases refute the statements of Harkness (7) and Von Schrenk (26, p. 75) that the mycelium does not grow after the death of the tree.

On dead down trees the sporophores were never half bell shaped or unguate, but were more typically near the subapplanate type.

Since so few cases of sporophores on dead fallen trees have been recorded during a rather extended period, it is safe to assume that infected fallen trunks are of slight importance from the standpoint of forest sanitation in infecting living trees through the production of sporophores.

Although sporophores are rather rare, an accurate indication of the place formerly occupied by a sporophore is supplied by the shot-hole cup (Pl. II), so termed and described by Meinecke (15, p. 23, 46). These shot-hole cups appear as cup-shaped depressions below a knot, the depression being riddled with numerous fine holes. At first they have the color of the freshly opened bark of the tree, but later become weathered and gray with age. They are formed in the following manner: The soft fleshly or cheesy sporophores issuing through knots are usually soon eaten by squirrels and microlepidopterous larvæ. Some of these larvæ then bore into the bark of the tree, where they are sought after by woodpeckers, which chop out a cup-shaped depression in the bark, corresponding to the place formerly occupied by the sporophores. This depression is riddled with what appear to be numerous fine shot holes, the burrows of the insect larvæ.

The presence of a shot-hole cup is just as reliable an index of dry-rot in a tree as is a sporophore. However, the same diagnostic values in relation to the age of the fungus plant in the tree, and consequently the extent of the resulting decay, must not be attached alike to sporophores and fresh and old shot-hole cups. An old, gray, weathered shot-hole cup would indicate the most extensive serious decay, while a fresh shot-hole cup, in turn, would indicate more extensive decay than a sporophore, since it is evident that more time must elapse before a shot-hole cup is formed than a sporophore and the longer the fungus plant lives in the heartwood the greater the amount of decay resulting.

The number of sporophores occurring on a standing living tree is typically one. Von Schrenk (27, p. 205) gives the number as usually one, but it must be remembered that at this time no description of *Polyporus amarus* had appeared, so it can not be stated definitely that Von Schrenk was referring to this fungus. However, Meinecke (15, p. 46, pl. 12) gives the number as typically one. Sometimes two have been found. As many as five shot-hole cups have been observed on a single living tree, but an examination of their con-

dition invariably showed that they had been developed successively, or at least not more than two in the same year. But on dead down trees the above rule does not hold. Of the seven known occurrences (see p. 9) several trees had two or more fresh sporophores.

During the course of the actual work of dissecting the trees exact data were secured on three sporophores and 17 shot-hole cups distributed on 15 trees, as follows: Two abortive sporophores on separate trees, one normal sporophore and two shot-hole cups on the same tree, 10 shot-hole cups on separate trees, 2 shot-hole cups on the same tree, and 3 shot-hole cups on the same tree.

That there might be a definite orientation of the sporophores in standing living trees was suggested by the work with *Trametes pini* of Möller (18), in which he found 89.4 per cent of the sporophores on the westerly side of the trees, attributing this to the facts that the prevailing winds were from the west, the trees were most strongly struck by rain on the west side, and therefore the branch stubs (a very common point of infection) were more moist on that side. Furthermore, he states that the sporophores appear at the same spot at which the infection commences. Weir and Hubert (32, p. 30), working with the Indian-paint fungus (*Echinodontium tinctorium*) on western hemlock (*Tsuga heterophylla*), found that most of the sporophores had a northwest to north-northeast orientation. However, the sporophores and shot-hole cups of *Polyporus amarus* are rather equally distributed to all points of the compass, showing no definite relation to any particular direction, and in not a single case was the sporophore developed at the same point at which the infection apparently commenced.

These sporophores and shot-hole cups occurred on trees ranging from 24.2 to 44.2 inches diameter breast high. The youngest tree which bore a shot-hole cup was 193 years old at stump height (1.5 feet), the next youngest was 221 years of age (28 years older), and the oldest, 379 years. Between the ages of 193 and 379 years the trees with sporophores or shot-hole cups were rather equally distributed. These figures are not given for the purpose of establishing a diameter breast high or age range for trees in which *Polyporus amarus* fruits; the number of trees examined forms entirely too meager a basis.

Sporophore formation did not seem to be in any way related to the width of the sapwood, since the sapwood in the trees which had formed sporophores varied from comparatively narrow in some cases to rather wide in others.

The heights at which the sporophores and shot-hole cups were found varied from 9.6 feet to 48.7 feet from the ground level, but thirteen of them occurred between 15 and 30 feet and only two at a greater height than the latter figure. Sporophores or shot-hole cups

always indicate that there is well-developed dry-rot in the heartwood. In such infections it is generally possible to distinguish three stages in the affected heartwood, with upper and lower limits. These stages for convenience are termed total extent, unmerchantable extent, and maximum concentration. "Total extent" is expressed by giving the height in feet in relation to the ground level of the lowest and highest point in the bole of the tree invaded by the fungus without regard to radial extent. By "unmerchantable extent" is meant the portion of the bole rendered valueless for lumber by the dry-rot, while "maximum concentration" covers that portion of the bole in which the decay seems to be at its worst. The upper and lower limits of all three of these stages may at times coincide, but especially that of the unmerchantable extent and maximum concentration. It is self-evident that these last two mentioned can never exceed the total extent.

The sporophores and shot-hole cups invariably appeared between the upper and lower limits of the maximum concentration. The lower limits varied from 3 to 25 feet below the sporophores or shot-hole cups, and the upper limits from 4 to 45 feet above them. In every case except one the lower limit of the unmerchantable extent was at 0. In other words the bole of every tree was unmerchantable, at least from the ground level to the sporophore or shot-hole cup. In the one exception the unmerchantable extent did not commence until 8.2 feet from the ground level. This was due to the presence of a large open fire scar extending from 0 to 10.8 feet. The fungus distinctly avoids the dried-out wood around open wounds, which habit will be fully discussed later in this paper. The upper limits of the unmerchantable extent were variable. In the two abortive sporophores the unmerchantable portion extended for 10 and 24 feet, respectively, above the sporophores, while the extent above the shot-hole cups was 23 and 53 feet.

The total extent in every tree with sporophores except one (see above, under unmerchantable extent) reached from the sporophore or shot-hole cup to the ground level, but the upper extent was variable, being for the two sporophores 24 and 25 feet, respectively, and for the shot-hole cups ranging from 24 to 53 feet.

From the figures available it is impossible to make an exact statement as to the range of the total extent, unmerchantable extent, and maximum concentration of the dry-rot in trees with sporophores or shot-hole cups, except that it may be safely assumed not only from the figures at hand but from observations on logging areas that the bole of a tree will always be unmerchantable from the ground level to a variable height above a sporophore or shot-hole cup. But it must be remembered that an old shot-hole cup indicates a greater development for the fungus plant in the tree than does the first

appearance of a sporophore or fresh shot-hole cup, and one should be influenced accordingly in judging the condition of a standing tree.

THE DECAY.

The dry-rot, described and pictured by Harkness (7), Von Schrenk (26, p. 68, pl. 2), and Meinecke (15, p. 46, pl. 12), is a very characteristic decay, most closely resembling the so-called peckiness of the eastern cypress (*Taxodium distichum*). Von Schrenk (26, p. 52-53) points to this analogy, even suggesting that the two diseases may be caused by the same fungus, but Long (12) has disproved this theory. The former investigator (29, p. 30) also calls attention to the macroscopical similarity between this dry-rot and the brown-rot of redwood.

Typically, the decay consists of vertically elongated pockets, varying in length from one-half inch to about a foot, which are filled with a brown friable mass, and the line of demarcation between the sound and decayed wood is very sharp. In some of these pockets small cobweblike or feltlike masses of white mycelium occur. The pockets are separated from each other by what appears to be sound wood, although in some cases streaks of straw-colored or brownish wood may extend vertically between two pockets. This is especially noticeable between young pockets. When immature the decay is faintly yellowish brown, soft and somewhat moist, and not broken up in the pockets. At times the mature pockets may be several feet long and rather broad; this type always occurs in connection with healed-over wounds, particularly healed fire scars in the butt of the tree. The decay has never been found in living sapwood and is usually confined to the heartwood of the trunk, but in very badly decayed trees the dry-rot sometimes extends into the heartwood of the larger limbs.

In the aggregate, the immature decay or advance rot extends but a short distance vertically in advance of the typical decay, and a distance of 2 feet beyond the last visible evidence of decay to the average eye will usually exclude all immature decay. This immature decay is very difficult to detect, occurring as it does in pockets, with the color in the very earliest stages differing but slightly, if at all, from the normal wood.

An occasional pocket may occur several feet in advance of the main body of decay, and while the wood of the pocket itself is of course greatly weakened, the intervening wood is probably very little affected, since the fungus hyphæ are very sparingly found between pockets of decay. In all, 566 trees containing typical dry-rot were dissected.

Typical dry-rot with small masses of white mycelium in some of the pockets is shown in Plate III.

STRUCTURE OF THE DISEASED WOOD.

The structure of the decayed wood in mature pockets was found to be practically as described by Von Schrenk (26, p. 70-71). In the very early stages of decay (immature pockets), cracks in the cell walls such as he describes for old pockets, which were most common in the pits, were rather rare. It was also found that cracks often started from the holes in the cell walls made by the hyphæ of the fungus. The color of the decayed wood varies from light to dark brown, depending on the state of decay.

In some of the decayed wood examined the bordered pits gave much the same appearance as is often presented by starch grains in a plant cell which have been partially corroded by diastase. Further examinations showed this condition of the bordered pits to exist in badly decayed wood, in slightly decayed wood, in the straw-colored wood between the pockets, and in sound wood. Immediately upon treatment with xylol, and more slowly with oil of turpentine, the pits resumed their normal smooth appearance; consequently, the condition is the result of a deposit on the membrane of the pits, but as to the nature of the substance deposited or the cause of its deposition the writer is unable to give any information. At least, the fact that the deposit was found on the pits in sound wood proves that it is in no way a result of the action of the fungus.

Badly decayed wood, slightly decayed wood, straw-colored and brownish colored wood between the pockets, and sound wood were treated with various reagents, the results in each case being practically identical. Anilin sulphate colored the cell walls a brilliant yellow. A cherry to violet-red stain was produced by treatment with phloroglucin and hydrochloric acid. Chloriodid of zinc and alcoholic iodine with sulphuric acid both stained the walls a yellowish brown color. After treatment for 12 hours with Javelle water, the wood turned a yellowish brown upon the application of chloriodid of zinc, and a brilliant yellow with the addition of anilin sulphate. The above tests demonstrate that the lignin compounds in the cell walls are not changed, in so far as our present knowledge of the nature of so-called lignin enables us to judge. Therefore, it seems probable that the fungus extracts from the cell walls either the cellulose or some other compound yet unknown.

THE MYCELIUM.

Hyphæ were very rare in the pockets of badly decayed wood or in the apparently sound wood immediately surrounding these. Proof of their having been quite commonly present, however, was afforded by the tiny holes in the cell walls of the decayed wood through which the hyphæ had passed. In the slightly decayed wood and the wood

immediately surrounding it hyphæ were found abundantly. They bore through the cell walls in all directions, showing no preference for the bordered pits and apparently making no distinction between spring and summer wood. They were rarely found in the medullary rays.

Harkness (7) states that "the mycelium does not leave behind the slightest microscopical trace of its presence in the sound wood when passing from pocket to pocket." In some of the brownish and straw-colored streaks of wood which extended vertically from pocket to pocket of immature decay, hyphæ were found sparingly. These usually followed the lumen of a tracheid, but sometimes passed through the wall into the lumen of the adjacent tracheid. The writer was unable to follow the entire course of the hyphæ in any case from pocket to pocket and therefore could not verify Von Schrenk's statement (26, p. 73) that "between the rotted areas the hyphæ usually extend directly from hole to hole." In some cases no hyphæ were encountered in the discolored streaks between the young pockets, but this was probably due to the failure to make sections at the proper place. Hyphæ were commonly present in the apparently sound wood surrounding young pockets to a distance of 4 mm. (0.157 inch), and sparingly from that point to 8 mm. (0.314 inch) in a horizontal direction. Owing to lack of proper material it was possible to make only a limited study of the vertical distribution of the hyphæ. In the case of the last (highest) pocket in a diseased tree the hyphæ were abundant to a distance of 1.5 cm. (0.6 inch) above the pocket, and sparingly from that point on to 7.8 cm. (3.07 inch), where they ended.

Observation leads to the inference that the hyphæ are able to pass for some distance through the sound wood without causing the slightest microscopical change in the color or structure other than an occasional hole in a cell wall as the hypha passes from the lumen of one tracheid to that of another. In certain cases isolated pockets of decay have been found at a maximum distance of approximately 4.3 meters (14.3 feet) from the nearest pocket of decay, yet a very careful analysis showed that there was only one possible means of entrance for the fungus into the tree, and consequently the hyphæ must have traversed this distance through the sound wood before causing another pocket of decay.

As to why the fungus decays only the wood in localized pockets which are separated by areas of practically sound wood it is impossible to state, since nothing is known of the influence of a possible variation of the chemical and physical properties of the wood on the fungus. Or it may be that the answer to the question lies in another direction; that is, the hyphæ in their work of destruction after a

certain time produce conditions unfavorable for their further development and are forced to seek another field.

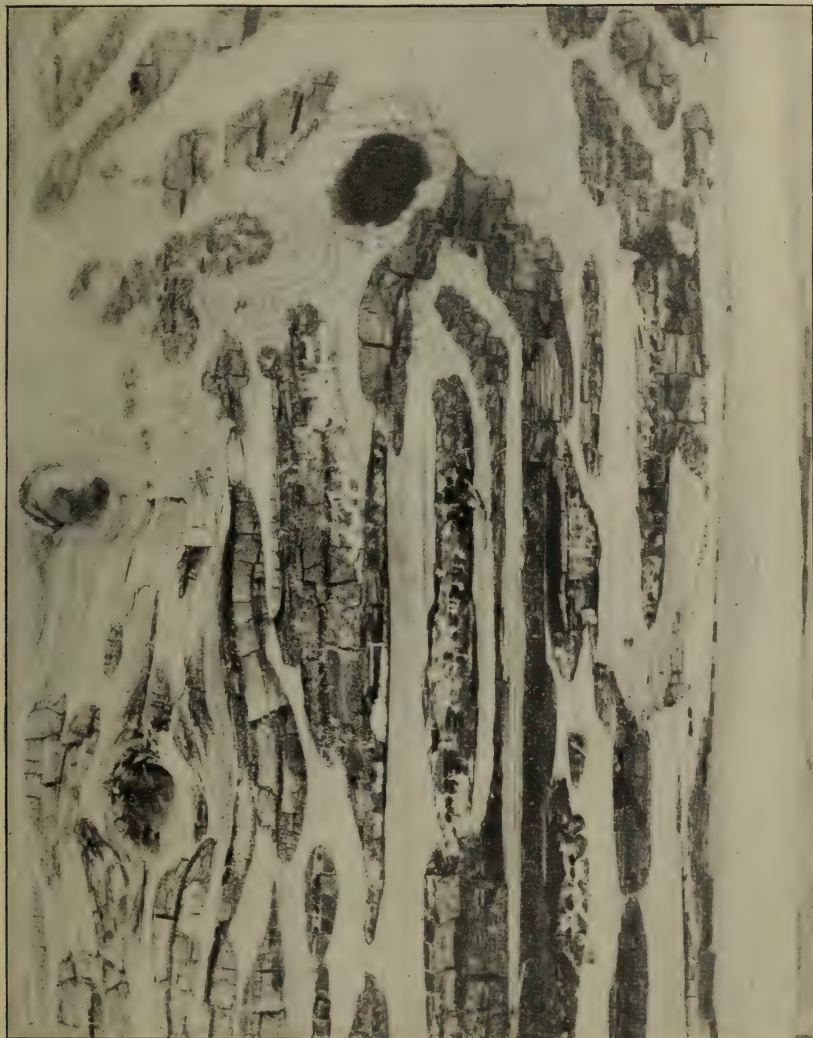
In the wood the hyphæ are hyaline, varying in diameter from 0.8 to 3.3 μ but being most commonly 0.8 to 1.7 μ , branching and rebranching into the finest threads, anastomosing, sparsely septate, rarely constricted at the septa, and sometimes having clamp connections. They never become so abundant as to fill the tracheids completely. Usually the hyphæ pass from the lumen of one tracheid into that of an adjoining tracheid and then extend up or down the lumen, but occasionally a single hypha may cross several tracheids in a radial or tangential direction without extending up or down their lumens or giving off any branches. The holes in the walls of the tracheids made by the hyphæ are very small, particularly so since the hyphæ are often sharply constricted when passing through the walls. Rarely the hyphæ are irregular in shape.

The hyphæ composing the cobweblike and feltlike masses of mycelium in the badly decayed wood (see p. 13) are usually hyaline, but sometimes have granular contents. They vary in diameter from 0.8 to 40 μ , are richly branched, more commonly septate than the hyphæ found in the wood cells, and sometimes constricted at the septa. No clamp connections were found. They frequently anastomose. They were often very irregular in shape, and globose or spindle-shaped swellings were frequent.

OTHER FORMS OF DECAY.

Besides the typical decay already described, two other very characteristic forms were found. One of these is characterized by small spots or pockets of brown decayed wood varying in width from 0.5 to 2 mm. (0.02 to 0.08 inch) and in length from 1 to 4 mm. (0.04 to 0.16 inch), with the long axis running vertically in the wood. In some cases larger decayed spots are formed by the joining of two or more smaller ones. The tiny decayed spots are separated by apparently sound wood. As for the structure of the decayed wood and its reactions with various reagents, these agree exactly with the typical form of dry-rot (see p. 14), and this decay is very probably an abnormal form of the typical decay caused by *Polyporus amarus*.

The other form of decay consists of very small white spots (measurements as given above) in which the wood has been reduced to cellulose, separated by apparently sound wood. The structure of the decayed wood is practically as described by Hartig (8, p. 53-54; 9, p. 36-37) for decay caused by the ring-scale fungus (*Trametes pini*), and the rot under consideration is undoubtedly caused by this fungus, since, through the courtesy of Dr. James R. Weir, the writer has been privileged to examine sporophores of *Trametes pini* with the typical



TYPICAL DRY-ROT IN INCENSE CEDAR CAUSED BY POLYPORUS AMARUS.

Photographed by Meinecke.

decay collected on incense cedar in Oregon. As far as the writer can ascertain, this is the only collection of its kind now known. Neither of these two decays affects the living sapwood.

The mycelium of both is the same and differs from the mycelium of typical dry-rot. Studies were made where these two decays were distinct, where they graded into one another, and where they graded into the typical dry-rot. The hyphæ vary from hyaline to dark brown in color, with a diameter ranging from 0.8 to 6.7 μ but most commonly 3 μ . The heavier brown hyphæ often branch profusely, the branches becoming smaller and lighter in color. The smallest ones are usually hyaline, and so are some of the larger hyphæ. In some instances the smaller hyphæ are merely continuations of the heavier strands. The hyphæ are sparsely septate, often constricted at the septa and without clamp connections. They bore through the cell walls in all directions, but seemingly more often through the tangential walls. No preference is shown for the bordered pits. They are characteristically sharply constricted when passing through the walls of the tracheids and have marked attachment organs. The hyphæ did not enlarge in the secondary lamellæ when boring through the wall, as is shown by Hartig (8, 9) for *Trametes pini*. Quite typically, a single strand may pass tangentially through as many as 20 or 30 tracheids, often completely traversing an annual ring, without sending any side branches into the lumens. This mycelium appears to agree closely with that described and figured by Von Schrenk (26, pp. 73-74, pls. 4-5), but which he assumed to be secondary and in no way connected with the dry-rot. Often the hyphæ seem to pierce a cell wall without developing in the lumen of the tracheid entered, a condition recorded by Hartig (8, p. 46) for *Trametes pini*. However, in so many cases unattached fragments of hyphæ were found in tracheids through the walls of which the hyphæ had penetrated without developing in the lumen that most probably the hyphæ did develop but were broken off in sectioning.

In all, 80 trees which contained one or both of these decays were dissected. The *Trametes pini* decay occurred alone in 61 of these, the dry-rot in small pockets in 11, and both forms in 8 trees. In 28 of the 61 trees having the *Trametes pini* decay, this was either intermingled, graded into, or very close to pockets of typical decay without there being any line of demarcation between the two. In certain cases the two decays could be absolutely traced to the same source of infection. Tree No. 40 on the intermediate area forms an excellent example. This tree had two small open fire scars in the butt just at ground level. There was a light infection of typical pockets of dry-rot extending from ground level to a height of 7.3 feet. At this point *Trametes pini* decay appeared without any line of demarcation and

extended to 29.4 feet, and then the typical pockets of dry-rot reappeared, which ultimately ended at a height of 41.4 feet. The only possible means of entrance for the two forms of decay were the small open fire scars at the ground level. A similar condition is presented in tree No. 7 on the intermediate area. This tree had a large open fire scar extending from the ground level to a height of 8 feet. Typical dry-rot entering through this open wound began at 6 feet, extending to 9.7 feet, where it merged into *Trametes pini* decay, which then gave place to the typical dry-rot at 14.7 feet, and the latter finally ended at a height of 20.7 feet. No line of demarcation could be distinguished between the two decays, and the point of entrance of the infection was at the open fire scar. Other examples could be cited, but these seem sufficient.

In the eleven trees in which the dry-rot in small pockets occurred it was either very close to or intermingled with typical dry-rot in six, and in four of these six trees both forms of decay could be exactly traced to a common point of entrance. There were no apparent lines of demarcation in any instance between the two forms of decay. In tree No. 392 in the intermediate range typical pockets of dry-rot extended from ground level to 28.7 feet. At this point the typical decay changed to the small pockets, and this form occupied the heartwood to 36.9 feet, where the decay stopped altogether.

Finally let us consider the eight trees in which both the dry-rot in small pockets and the *Trametes pini* decay were found. In two of the trees the two decays occurred in different parts of the bole. In two trees the decays were very close together, while in four trees the two were accompanied by pockets of typical dry-rot. Tree No. 296 on the intermediate area offers an excellent illustration of this last condition. In this tree the dry-rot in small pockets, the *Trametes pini* decay, and typical pockets of dry-rot were intermingled, and transition stages between the three forms were apparent from ground level to a height of 30.3 feet. In four of the eight infected trees it was possible to trace the entrance of both decays to the same point, healed fire scars. There were no lines of demarcation separating the various decays.

The interesting point in connection with the two forms of dry-rot and the decay caused by *Trametes pini* is that they occurred in the same substrata, either merging into one another or actually intermingling without any well-defined lines between them. That such lines of demarcation between different decays are the general rule has long been accepted and has been most recently expressed again by Weir (31). Hence, it is particularly interesting to find two exactly opposite types of decay intermingling so freely. It is quite probable, however, that such occurrences in the future will come to be recognized as quite common. The writer has already found

decays caused by *Trametes pini* and by *Fomes laricis* (the chalky quinine fungus) intermingled in the wood of living Douglas firs on several occasions, while down logs in the woods are often mycological gardens of wood-destroying fungi with the decays completely intermingled.

Both the dry-rot in small pockets and the *Trametes pini* decay are nearly always found around decayed knots or following along healed wounds, mainly those caused by fire. Where the infections occur around knots the decay is almost invariably confined to the immediate neighborhood of the knot, resulting in little or no loss in the merchantable contents of the tree. Where any appreciable quantity of wood was rendered unmerchantable, the decays were almost invariably in intimate connection with healed-over wounds caused by fire, frost, or lightning, particularly the first, throughout their extent. Exceptions to this rule did occur. In one tree, for example, the *Trametes pini* decay extended for a distance of 23.5 feet in the center of the tree above an open fire scar without being in connection with any other wound. But the fire scar was very large, extending deeply into the tree and undoubtedly had a far-reaching influence on conditions in the heartwood. In another tree (tree No. 40 on the intermediate area; see p. 17) this same decay extended for 22.1 feet in between two areas of typical dry-rot without following along any wound. The dry-rot in small pockets was found in one instance to extend for a distance of 8.2 feet, not in connection with a wound but merely as an extension of typical dry-rot. This case has already been cited (tree No. 392 on the intermediate area; see p. 18).

The above fact suggests that the dry-rot in small pockets may be the result of the influence on the dry-rot fungus of changed conditions in the heartwood, either physical, chemical, or both, induced by the presence of wounds or knots.

In further support of this hypothesis, it is almost invariably the rule wherever typical dry-rot is found along healed fire scars in the butt of a tree that instead of the pockets of normal size, one or more long continuous pockets of the dry-rot follow immediately along the scar throughout its length and invariably run out close to the end of the scar. A maximum length of 10 feet has been attained. Such pockets have never been found except in connection with wounds. This seems to prove that variations in the typical form of dry-rot may be induced by certain types of wounds in the tree.

The fact that the *Trametes pini* decay is usually found in the immediate vicinity of knots or healed-over wounds may be taken to indicate that incense cedar is an unsuitable host for *Trametes pini* and that the organism can rarely progress much beyond the point of infection. This would also explain the rare production of sporophores and the fact that in the only known collection, to cite Weir's

words in a letter to the writer, "The sporophores are of the small depauperate type which I find occasionally on trees at high elevations or on old punk knots from which the original sporophores have fallen and are reviving."

However, for the purposes of this paper these decays may all be treated as one and the same, since the dry-rot in small pockets and the *Trametes pini* decay are of negligible importance both in the number of infections and amount of cull resulting. Hence, except in the data on the rate of spread of the dry-rot, they are included in all subsequent pages with the typical decay of *Polyporus amarus*.

No relation was found between the width of the sapwood and the extent of decay; trees with wide and narrow sapwood seem to be equally affected with the dry-rot.

RAPIDITY OF SPREAD OF THE DRY-ROT.

Although the rapidity of the spread of decay caused by heartwood-inhabiting fungi in standing trees has always been of interest, very little work has been done on this line. Hartig (9, p. 115-116), mentions this briefly in relation to the rot caused by *Polyporus (Fomes) igniarius* in oak. More recently Münch (23) has published some interesting results from studies of the same fungus and host, showing a wide variation of 3.8 to 37.5 cm. (0.12 to 1.23 feet) in the yearly vertical progress of the decay, with an average of 5 to 9 cm. (0.16 to 0.30 of a foot). No tangible difference was found between the upward and downward rate of spread from the point of infection. Münch's results are based on an analysis of only 15 cases, and their value is further reduced by the fact that in determining the age of the infection which entered a tree through an open wound, he assumed that infection must have occurred the year the wound was made, or at least a very few years subsequently, even though the wound was still open at the time of analysis. True enough, as shown by Münch (23), *Fomes igniarius* attacks not only the heartwood but the sapwood of many trees and kills the cambium, causing cankers with subsequent callusing, and by counting the number of annual rings in the callus at the point of infection the age of the decay can be determined, provided a canker was formed the year of infection; but this is not uniformly the case, to judge from Münch's (23, p. 519) own statement that "*Fomes igniarius* produces exceedingly variable cankers. Sometimes small points of infection which are scarcely noticeable and are soon healed perfectly . . ."

In securing the figures on the yearly rate of spread of the dry-rot, only those infections were considered the entrance of which could be absolutely traced, without any other possibilities, to a healed scar for which it was possible to determine the exact dates of occurrence and closure. For example, an infection is found in a

tree which was cut in 1915. The fungus entered through a healed fire scar which occurred in 1781 and was completely closed by callusing in 1816. By subtracting 1781 and then 1816 from 1915 it is seen that the fungus has been in the heartwood a minimum of 99 and a maximum of 134 years. During this period resulting decay has progressed a vertical distance of 34.2 feet in the bole, or a yearly average of 0.25 to 0.34 of a foot. The radial extent of the decay is disregarded, since this is of little importance from a practical viewpoint. Any serious infection usually extends more or less throughout the heartwood in a radial direction. Of course, the above method does not give a single figure for the yearly average progress of the dry-rot, but it does give the exact minimum and maximum limits between which the true figure lies.

In all 99 infections were possible of analysis by this method. The great majority of these commenced at ground level, entering through fire scars and extending up the bole. Ten of the infections were traced to wounds high enough up on the trunk, however, to make possible a comparison of the upward and downward progress of the dry-rot. This meager basis indicated that the dry-rot, in the main, progresses more rapidly downward than upward, although in individual cases this relation may be reversed.

The yearly progress of the decay is exceedingly variable. At one extreme there is a tree in which the fungus had been vegetating between 124 and 135 years, but the resulting dry-rot had only attained a length of 0.4 of a foot, or a minimum average yearly progress of 0.002 and a maximum of 0.003 of a foot. The tree was 147 years old. At the other extreme, the fungus in from 10 to 58 years caused decay extending over 30.9 feet of the bole of another tree, that is, a minimum average progress of 0.53 of a foot a year and a maximum of 3.09 feet. This tree was 240 years old. Again, in a 107-year-old tree the fungus caused a decay with a minimum average progress of 0.87 of a foot and a maximum of 1.90 feet a year, extending a total of 40 feet vertically. In the main, however, the minimum progress of the dry-rot varied from 0.01 to 0.20 of a foot a year, while the maximum ranged from 0.01 to 0.35 of a foot. Higher yearly rates than the upper limits stated were not uncommon, but lower rates than 0.01 of a foot were rare.

These figures clearly demonstrate the slow progress of the dry-rot fungus in causing decay. Generally it required from 50 to 300 years to bring about any far-reaching dry-rot. In the heartwood of certain individuals the fungus had vegetated for decades, the resulting decay only extending 1 or 2 feet from the point of infection. A similar condition was found by Münch (loc. cit.) for *Polyporus* (*Fomes*) *ignarius* attacking oak. As to why the development of the dry-rot fungus in certain cases is so inhibited the writer is unable to present

any definite information, but certainly the chemical and physical condition of the substratum must have a strong bearing on this phenomenon. Hartig (9, pp. 115-116) believes in the case of *Polyporus* (*Fomes*) *igniarius* that the width of the annual rings of the wood is not without influence on the rapidity of decay. Münch (20, p. 156) states that the more rapidly grown coniferous wood, consequently that with the broader annual rings, is more speedily decayed by *Fomes annosus* than slower grown wood with narrower rings, even extending this to broad and narrow rings in the same individual. Later (22, p. 403-406), he shows that suppressed individuals of beech artificially infected with *Stereum purpureum*, *S. rugosum*, *Polyporus* (*Fomes*) *igniarius*, and *P. (F.) fomentarius* were more seriously decayed than dominant thrifty trees, yet it is just such suppressed trees which must have the narrowest annual rings. Finally (23, p. 521), the same investigator finds no relation whatsoever between the breadth of the annual rings and the rapidity of decay in the wood of oak attacked by *Polyporus* (*Fomes*) *igniarius*.

PURPLE COLORATION.

Accompanying the dry-rot is a purplish coloration of the heartwood which is very characteristic. The writer does not find this mentioned in any description of the dry-rot so far available, but it is well known to the lumberman. This color varies from a light salmon-red or pink to a pronounced purplish red in trees with heavy decay, where it may stand out strongly in cross section as a ring surrounding the decayed area or present a mottled appearance over the entire heartwood. Where the coloration is faint it is sometimes impossible to detect it in cross section, but if the tree is split longitudinally the color is readily apparent, although it often fades out entirely after several days' exposure to light and air. It usually commences at ground level and extends upward, but may start at varying heights.

Microscopical studies of this colored wood did not show any deviation from sound wood. No hyphæ were found except at points immediately adjacent to pockets of dry-rot. No chemical or physical examination was possible.

In all, 634 trees were dissected in which the purple coloration was present. The notes from Cow Creek did not include data on this coloration. The youngest tree in which the coloration was present had an age of 72 years, while the youngest tree cut was 52 years old. No attempt can be made to set a minimum age limit for trees with purple coloration, since not many trees were cut below the age of 70 years.

Of the 634 trees under consideration, the purple was present in 84 in which no dry-rot was found. In these the coloration, varying through all shades from a very faint salmon pink to pronounced red-

dish purple, usually began at the ground level, extending up the heartwood to a minimum height of 2.6 feet and a maximum height of 31.4 feet. Of these trees 39 had open or healed-over wounds, mainly caused by fire, offering or having offered a means of access for the dry-rot, but the remaining 45 were without indications of wounds, the only possible mode of entrance for the decay being through branch stubs. It would be highly improbable that all of these trees could be infected by the dry-rot fungus without showing any indications of decay, so the conclusion is obvious that purple coloration may exist unaccompanied by *Polyporus amarus*.

In all, 510 trees with typical dry-rot alone or in conjunction with secondary decay were worked up at Sloat, Strawberry, and Crockers Station. Notes on 25 of these were incomplete so far as purple coloration is concerned, so they drop out of consideration. All but 17 of the remaining 485 had purple coloration accompanying the decay. In certain cases the coloration did not extend over the entire decayed area, running out before the decay ended, or else isolated pockets of dry-rot were found outside the area of coloration. In the 17 cases of dry-rot unaccompanied by any coloration, the decay as a rule was negligible. In four of these trees, however, there was a loss in volume caused by the dry-rot of 7.1, 21.3, 39, and 67 per cent, respectively, without any coloration being visible, indicating that serious decay can exist apart from the purple coloration.

Of the 59 infections of the *Trametes pini* decay, 4 became impossible of consideration because of incomplete notes. Of the remaining 55, 12 were unaccompanied by purple coloration, but all of these except two were very superficial infections. Even in these two the amount of cull was very small. This decay had already been shown almost invariably to follow wounds in the trees; hence, it becomes quite reasonable to presume that the absence of purple coloration was brought about in most instances by the change in the physical or chemical condition of the heartwood induced by the influence of the wounds.

Where the typical decay and the *Trametes pini* decay were intermingled the coloration was almost invariably present, although not always throughout the entire infected wood. This was also the case with the brown dotlike pockets. However, these data should not be judged as more valuable than indications, since the number of cases available was relatively few.

Secondary rots comprised 43 infections; only 12 of these were in conjunction with purple coloration. The 31 without coloration only yielded one cull case; the amount of unmerchantable volume was very small, and furthermore these secondary rots were almost invariably in connection with healed or open wounds.

Hence, on account of the failure to find any microscopical evidence of fungous action in purple wood, the presence of dry-rot outside the area of purple coloration in certain trees, the frequent occurrence of extensive coloration in trees free from dry-rot, combined with the usual presence of the purple coloration in wood badly enough decayed by *Polyporus amarus* to cause a noticeable reduction in the merchantable contents of the individual tree, while it may be more often absent in light infections, the conclusion appears obvious that purple coloration is not a result of the action of the fungus, but, on the contrary, if it bears any relation whatever to the dry-rot, is merely a condition of the heartwood inducing favorable development of the vegetating hyphæ. The fact that the *Trametes pini* decay is more often unaccompanied by the coloration is offset by such infections usually being superficial and following wounds which probably exert a profound influence on the heartwood. No relation was found between the purple coloration and the width of the sapwood. Trees with sapwood varying from very narrow to very broad alike had the coloration in the heartwood.

RELATION OF DRY-ROT TO AGE AND CONDITION OF THE TREE.

From previous hints in the literature (22, p. 403-406; 23, p. 520; 16, p. 18-19, footnotes), Meinecke's preliminary study on incense cedar and his later work on white fir (16), it was reasonable to assume that some relation should exist between dry-rot and the age and condition of the tree; i. e., the degree of dominance and suppression.

Münch (22, p. 405), working with artificially infected red beech, found suppressed trees more susceptible to decay by *Polyporus* (*Fomes*) *igniarius*, *P. (F.) fomentarius*, *Stereum rugosum*, and *S. purpureum* than thrifty, dominant ones and explains this by the theory that the wood of suppressed trees contains a greater amount of air, consequently more oxygen, than thrifty dominants. In previous experiments the same investigator (19, 20, 21) had brought out the strongly favorable influence of oxygen in the host tissues on the development of wood-inhabiting fungi. Meinecke (16, p. 48) recognizes three periods in the life of white fir in its relation to the stringy brown-rot caused by the Indian-paint fungus (*Echinodontium tinctorium*): (1) The age of infection, at which "the infection rarely leads to more than negligible decay unless the tree is handicapped by quite unusually severe conditions, such as very large old wounds;" (2) the critical age, which "marks the point after which a combination of pronounced suppression and heavy wounding generally results in distinct decay;" and (3) the age of decline, "when even dominant (that is, thrifty) trees become subject to extensive and intensive decay." The relation between decay and suppression is brought out.

The crown class, as determined by observation of the standing tree, expresses the past history, more or less strongly modified by conditions prevailing through a varying number of years previous to the time of observation; it may not give the real past history of the tree. "Dominance" and "suppression" are really incorrect terms, used for lack of better ones. They are based on the relation of the height of one tree species to others in the same stand. In this case height alone would be misleading. For example, consider a more or less second-story species in a mixed stand, in which category incense cedar falls. Practically all the trees would be included in the intermediate or suppressed classes when related to other species in the stand, thus entirely obscuring the true relation of the individuals within the second-story species. On the other hand, it is an exceedingly difficult undertaking, often leading to grave error, to attempt classification by the observation of individuals in a mixed stand with relation to other individuals of the same species.

For our purposes we can not consider other tree species, but must compare individual trees with others of the same species. But here, also, height alone is not the deciding factor. Instead of giving dominance and suppression in the current meaning, these terms are expressed by the relation of the actual volume of the tree to the average volume of trees of the same age. Therefore, it was necessary to "curve" data collected on a number of trees to secure average volumes by age. Only trees of normal form with exact ages and free from severe wounds, malformations, and other seriously injurious factors which would interfere with the correct computation of the volume were used. Curves were constructed for the intermediate area and for the optimum area, since it was apparent that the volumes by ages would be much higher for the last-named areas than for the first, which fact was strongly brought out by the resulting curves. These curves are presented in figure 1, the higher curve based on 461 trees representing the optimum area and the lower based on 340 trees, the intermediate area. The National Forests on which these areas were located are also indicated. Thence, the trees for the intermediate area and for the optimum area were rated in regard to their respective curves, those with a volume higher than the average given by the curve for the same age being classed as dominant and those with a lower volume as suppressed. At first, an intermediate group was selected by designating an arbitrary volume above and below the average volume, trees between these limits being classed as intermediate. However, it was found that such trees inclined either toward the dominant or the suppressed in their characteristics, depending on whether they were above or below the average in volume for the same age. Furthermore, it was exceedingly difficult

to determine just what the limits of the intermediate class should be, so in order to preclude any error in judgment the procedure as first stated of establishing just two classes, dominant and suppressed, to include all the trees, is followed throughout.

The method of obtaining the volume of the tree in cubic feet requires a little explanation. Each tree was considered as a perfect cone over the stump, at which the age count had been taken, in order to obtain directly comparable figures for the different ages. Figures from normal trees showing the relation of the diameter breast high to diameter of butt at stump height (1.5 feet) were plotted and curved, the strongest portion of this curve lying between 10 and 50 inches diameter breast high. From this curve a table expressing

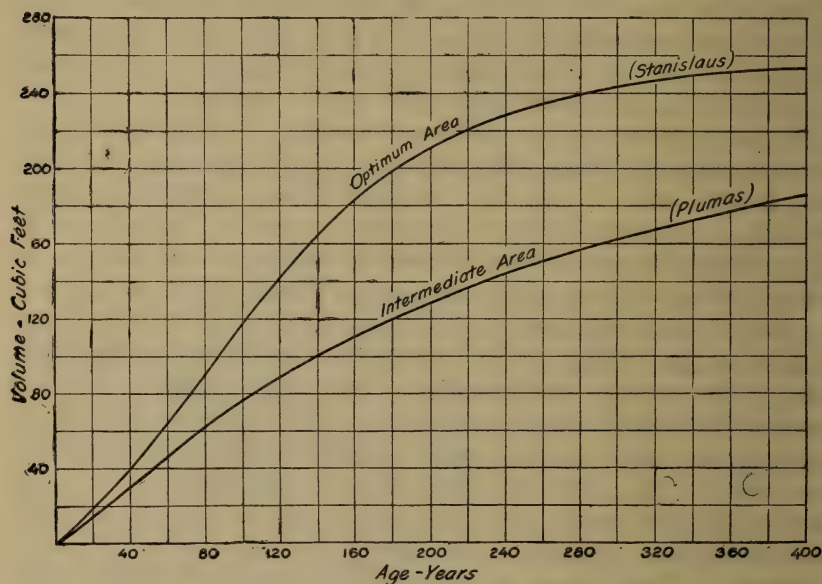


FIG. 1.—Comparison of average volumes of incense cedar on the optimum and intermediate areas.

the relation of the diameter breast high to diameter of butt at stump height for each inch class was read. It was then a simple matter to secure the diameter outside the bark at stump height for any tree, no matter how irregular the stump might be, due to wounds or other factors, and combining this with the height to work out the total cubic contents. Loss of volume caused by wounds or other factors was disregarded. In other words, each tree was treated as if it was absolutely normal. Let it be emphasized again that the volumes obtained were not meant to be an exact expression of the actual volume of each tree to the last cubic foot but merely had to be directly comparable to each other for the various ages.

In considering the trees with decay, each separate focus of dry-rot is termed an infection, and there may be two or more infections in

the same tree, each one, however, the result of a separate and distinct inoculation. As soon as an infection causes a measurable amount of cull it becomes a cull case and is so termed. Hence, every infection is not a cull case, but every cull case is an infection. Only loss of merchantable timber through dry-rot is considered; cull from wounds, knots, limbs, insect borings, or crook is disregarded, since these have no bearing on the loss from dry-rot except when the decay is directly traceable to a wound. In such cases loss from the wound is included with the volume of rot.

For figuring from the field notes and measurements the cull caused by dry-rot, the amount and degree of damage with relation to the resulting loss in merchantable lumber was carefully taken into account, just as it is in scaling. For example, a cull case might have considerable linear extent but consist only of a few scattered pockets in a straight line, resulting in little or no loss in merchantable volume. The same number of dry-rot pockets, shorter in linear extent but radially scattered throughout the heartwood, probably would cause considerable cull. Again, a number of pockets close to the sapwood, mostly slabbing out when the log is sawed, would have far less weight than the same pockets in the center heartwood. Meinecke's method (16, p. 37) of considering the entire bole of the tree over the linear extent of decay as cull, while justifiable with the commercially inferior white fir, could not be applied to the distinctly more valuable incense cedar. Here the lateral extent of the decay also had to be taken into account. This could be readily determined from the field notes and diagrams. For example, if the decay occupied one-fourth of the area as seen on cross sections and had a linear extent of 10 feet, the volume outside the bark of this 10-foot frustum (the tree being considered as a cone, see p. 26) was first secured and then one-fourth of it was considered as the volume of the decayed portion of the tree. Below one-fourth the decay was usually treated as negligible except when it had a linear extent of several feet. The volume was then computed as before.

Separate tables containing the above figures were worked up for the four areas, the trees being arranged progressively by ages, beginning with the youngest. It does not seem necessary to present these tables, since they were merely preliminary.

In considering the trees on the intermediate area it was found that the first infection which resulted in cull occurred in a tree 98 years old. However, infection can take place at a much earlier age than this. For example, in a tree 104 years old there was a light cull case traced to a healed lightning wound. The tree was injured at the age of 50 years and the wound completely healed when the tree was 63 years old; hence, the tree could not have been older than 63 years at the time of infection. Again, in a tree 146 years old there was a

serious cull case traced to a healed fire scar. This wound healed when the tree was 38 years old; hence infection could not have occurred subsequent to that age, since the field notes seem to exclude any possibility of an entrance of the dry-rot through a knot. Numerous other examples might be cited, but none of them reduces the minimum age of possible infection below 38 years.

An analysis of infections definitely traced to healed wounds in trees on the optimum area places the earliest age at which trees may be infected at 34 years, and this may be accepted as the age of infection for all the areas, since there is no apparent reason other than chance as to why the various areas should differ in this respect. Infections were very common between the ages of 45 and 80 years. No tendency was apparent toward an earlier age of infection in suppressed than in dominant trees, or vice versa. The foregoing figures are based on an analysis of 99 infections. Of course, this age may be even lower than here indicated, but it is evident that the earliest age of infection can not be lower than the age at which heartwood formation takes place in incense cedar. Just when this occurs is not definitely established, but observation seems to place it somewhere around 20 to 30 years. To be sure, there is a possibility of infection taking place in pathological heartwood resulting from an injury before the true heartwood is formed, the fungus mycelium vegetating in this type of heartwood until such time as true heartwood develops and then attacking it. While absolute proof of this course of procedure is lacking, observations have all tended toward substantiating the theory.

Furthermore, this age agrees approximately with that found by other workers with different species. Meinecke (16, p. 47) finds that for white fir (*Abies concolor*) decay caused by the Indian-paint fungus (*Echinodontium tinctorium*) "may show in trees 60 years old or perhaps younger," while Weir and Hubert (32, pp. 17-18), working with the same fungus in western hemlock (*Tsuga heterophylla*), set the average infection age for one type at 44.5 years and for another at 57.3 years. The figures are obtained by the use of a formula applied to the younger age classes. These same workers (33, pp. 11-12) place the "age of earliest infection" at about 50 years for western white pine (*Pinus monticola*) attacked by several common wood-destroying fungi.

Interesting as the determination of the age of infection or the age of earliest infection may be from an academic viewpoint, it is of little practical importance in this region. The questions of real import in this as in other species are the age at which decay begins to result in cull of economic importance and whether there is any relation between this and dominant and suppressed trees. The trees on the intermediate area and on the optimum area were first arranged

by 40-year age classes, grouping dominant and suppressed trees separately, and the percentage of dry-rot was determined for each age class. This was done by relating the total volume of dry-rot in each age class to the total volume in cubic feet of the trees in that age class. From these tables it was apparent that while there was no tangible difference between the amount of decay in the dominant and suppressed trees on the intermediate area, on the optimum area there was a decided difference, most strongly shown in the younger age classes, the dominant group having a lower percentage of decay than the suppressed trees.

That the trees in the intermediate area fail to bear out the relationship between suppression and decay indicated by the results of other workers on different species is after all logical. The reason for this is not hard to find. These trees are in the intermediate range for incense cedar, where the growth on the whole is relatively slow, and while they may be placed in dominant and suppressed groups within themselves, yet in relation to the trees in the optimum range they are slow growing, practically all being included under suppressed, with a few dominants. In other words, most of these trees are under the influence of regional suppression. Another glance at figure 1, which shows the great disparity between the volume-age curves for the two regions, brings this out more clearly. The term "regional suppression" is a new one. However, the concept which it embraces has long been advanced in ecology and silviculture. That there is a marked decrease in vigor and a decline in the rate of growth for each tree species outside its optimum, becoming greater as the distance from the region of best development increases, until finally the species becomes completely suppressed by other species either in or closer to their own optimum, has been pointed out by Mayr (13, pp. 73-79). This is exactly what has happened to incense cedar in the intermediate range. At best a second-story tree, in this region, away from its optimum, it has become, except for a few scattered individuals, badly suppressed by Douglas fir, Jeffrey pine, and yellow pine, which, while not in their own optimum, are yet closer to such a condition than the incense cedar. Mitchell (17, p. 33) recognizes how far this may go in suggesting that it may be advisable to eliminate the species entirely on the sites less adapted to it.

An analysis of the field notes reveals that this regional suppression is not due to a pathological condition, which might be suspected from the presence of the mistletoe (*Phoradendron juniperinum libocedri*) or of the needle and twig parasite (*Gymnosporangium blasdaleanum*).

A comparison of the trees on the intermediate area with the volume-growth curve for the optimum area resulted in the classification of only 38 out of the total of 495 trees as dominant. In other words, 457 of the trees on the intermediate area are actually suppressed when compared to the average for the optimum area.

It is not to be expected that the growth habits of the dry-rot fungus would vary to any extent in regions so closely related climatically as the intermediate and optimum ranges of incense cedar; therefore, it is reasonable to believe that no matter what the classification of the trees on the intermediate area may be in respect to dominance and suppression when compared with the volume-growth curve for that area, to find the true relation of the dry-rot fungus to dominant and suppressed trees it will be necessary to determine the classification of each tree by comparison with the volume-growth curve for the optimum area.

This is brought out in Table II, in which the trees from all the areas are combined, the dominance or suppression of all the trees being determined by comparison with the volume-growth curve for the optimum area. Only trees in which the progress of the decay or a fire scar did not make it impossible to determine the age at stump height are included in this table. This explains the slight discrepancy between the total number of trees dissected and the total number included in this and subsequent tables.

TABLE II.—*Cull caused by dry-rot found in incense cedars of the combined areas.*

Age class.	Number of trees (basis).		Average age.		Cull caused by dry-rot (percentage of the total volume).	
	Dominant.	Suppressed.	Dominant.	Suppressed.	Dominant.	Suppressed.
0 to 40 years.....	0	1	.....	40	.....	0
41 to 80 years.....	8	43	74	57	0	1
81 to 120 years.....	60	125	105	105	4	2
121 to 160 years.....	66	218	142	140	4	4
161 to 200 years.....	42	191	180	179	7	12
201 to 240 years.....	34	84	223	222	19	26
241 to 280 years.....	15	79	265	258	52	40
281 to 320 years.....	7	42	301	294	68	60
321 to 360 years.....	3	16	341	332	68	66
361 to 400 years.....	2	2	372	368	83	68
401 to 440 years.....	0	2	.....	436	.....	5
Combined.....	237	803	166	173	16	20

In Table II the dry-rot percentage in the age class 161 to 200 years, for example, is figured on the total volume of all the dominant trees both sound and decayed in that age class and not on the total volume of both dominant and suppressed trees. This is the method used throughout the table.

It will be noticed that the number of trees (basis) in the suppressed class far exceeds the dominant, this being a direct result of the influence of regional suppression on the trees of the intermediate area.

The columns of greatest interest are the last two, in which the dry-rot percentages of the dominant and suppressed trees in the different age classes are directly comparable. By dry-rot percentage is meant the percentage of cull caused by the decay resulting from

the work of the dry-rot fungus. The reader should remember that the percentage of cull based on the merchantable volume of the trees would be higher than the percentages here given, since these are based on the total volume of the trees outside bark and including the entire top. In the younger age classes up to 160 years the percentage of cull is small and variable, in one class higher in the suppressed, in another higher in the dominant, and in a third equal. But in the age class of 161 to 200 years a decided jump in the percentage of cull occurs, particularly in the suppressed trees. While the increase in the case of the dominants is only 3 per cent, in the suppressed trees it amounts to 8 per cent, bringing the cull percentage to 12. In the next age class a still further change is apparent. Here the cull percentage in the dominant trees increases strongly, as does also the percentage in the suppressed trees, the latter still remaining considerably higher than the former. But in those subsequent classes which have a sufficient numbers of trees to make the data of value, the cull is higher in the dominant than in the suppressed trees. When the age classes are combined, the total cull is 4 per cent more in the suppressed than in the dominant trees.

The salient features shown by Table II are the low percentage of cull in the younger age classes, the sudden increase earlier in the suppressed than in the dominant trees, which after it once begins goes steadily on with advancing age, and the higher percentage of cull in the suppressed trees as compared with the dominant trees in the two age classes which show the first sudden increase in this percentage.

However, the percentage of cull caused by dry-rot is not the only figure of interest, since it is prerequisite that the trees first be infected and that these infections develop sufficiently to cause measurable cull. Table III gives the figures on percentage of infection and cull cases. The number of trees used as the basis and the average age are the same as in Table II.

TABLE III.—*Infections and cull cases found in incense cedars of the combined areas.*

Age class.	Infections (percentage of total number of trees).		Infections causing measurable decay (percentage of total cull cases).	
	Dominant.	Suppressed.	Dominant.	Suppressed.
0 to 40 years.....		0		0
41 to 80 years.....	12	5	0	5
81 to 120 years.....	50	33	28	15
121 to 160 years.....	62	42	35	28
161 to 200 years.....	57	62	36	44
201 to 240 years.....	71	74	56	63
241 to 280 years.....	87	82	80	78
281 to 320 years.....	100	90	86	88
321 to 360 years.....	100	87	100	87
361 to 400 years.....	100	100	100	100
401 to 440 years.....		100		100
Combined.....	61	54	41	42

Table III shows that the percentage of infections is not in exact relation to the percentage of cull caused by dry-rot as given in Table II. In the age class of 41 to 80 years, while the percentage of infections is higher in the dominant trees the percentage of cull is slightly lower. In the age class of 81 to 120 years these percentages bear the same relation to each other as they do in all other classes except the classes of 121 to 160 years and 361 to 400 years. In the former there is a much higher percentage of infections in the dominant trees, while the percentage of cull is equal, and in the latter the percentage of infections is the same in both dominant and suppressed trees, while the percentage of cull is higher in the former. For all the age classes combined the percentage of infections is markedly higher in the dominant than in the suppressed trees.

Now, considering the columns relating to the total trees with cull cases, that is, where infections cause a measurable amount of decay, it is found that in the age class of 41 to 80 years none of the infections in the dominant trees result in cull cases, while all of the infections in the suppressed trees do, thus accounting for the higher percentage of cull in the suppressed trees in that class. In the next age class (81 to 120 years) the dominant trees have almost twice as many cull cases as the suppressed, and the percentage of cull is just twice as great in the former. But in the age class of 121 to 160 years, while the cull cases are in a higher percentage in the dominant trees the percentage of cull is equal in the two classes, showing that there is more loss per cull case in the suppressed than in the dominant trees. In the subsequent age classes the cull cases and the percentage of cull are in the same general relation except in the age class of 361 to 400 years, where the difference is the same as explained for the infections. The total cull cases for the suppressed trees is only 1 per cent higher than for the dominant trees.

The idea might have been advanced that since inoculation by spores of any wood-destroying fungus is to a certain extent a matter of chance, the greater percentage of cull in the suppressed trees might have been due to a greater number of infections in these trees. But Table III shows more infections in the dominant trees, while the cull cases are about equal in both. Therefore the cull cases must be more severe in the suppressed trees.

The infections, or even the cull cases, do not show the same progression through the age classes from the youngest to the oldest as is shown by the cull percentage. In the former the sudden, sharp increase in the age class of 161 to 200 years for the suppressed and in the class of 201 to 240 years for the dominant trees is not apparent. The increase is more regular throughout, thus indicating that there is an influence other than merely the number of infections which has

a strong bearing on the development of cull cases and the percentage of cull.

Since neither the total number of infections nor cull cases follows the same law as the percentage of cull, it is self-evident that there must be an exact relation between this last and the more extensive or severe cull cases. Accordingly, in Table IV the severe cull cases, that is, those cases in which one-third or more of the total volume of the tree is a loss through dry-rot, are considered separately. The same basis is used as in Tables II and III and the percentages are based on the number of trees in the dominant and suppressed groups considered separately in each age class.

TABLE IV.—*Relation between dominant and suppressed trees in severe cull cases found in incense cedars of the combined areas.*

Age class.	Severe cull cases (per cent).		Age class.	Severe cull cases (per cent).	
	Dominant.	Suppressed.		Dominant.	Suppressed.
0 to 40 years.....		0	281 to 320 years.....	71	66
41 to 80 years.....	0	0	321 to 360 years.....	67	81
81 to 120 years.....	3	2	361 to 400 years.....	100	50
121 to 160 years.....	2	2	401 to 440 years.....		100
161 to 200 years.....	5	14			
201 to 240 years.....	25	31	Combined.....	14	17
241 to 280 years.....	73	48			

In Table IV is seen the same form of progression for the severe cull cases as was shown for the amount of cull in Table II. Low percentages in both groups up to an age of 160 years, with a sudden increase in the percentage of severe cull cases in the age class of 161 to 200 years for the suppressed group are followed by a like increase in the class of 201 to 240 years for the dominant trees. After 240 years is passed there is a higher percentage of severe cull cases for the subsequent age classes in the dominant group, just as is the case for the percentage of cull. The only exception to this is found in the class of 321 to 360 years, where the relation is reversed.

The outstanding fact shown by Tables II, III, and IV is that incense cedar during the earlier stages of its life, even though heavily infected, is able to retard the progress of the dry-rot fungus in causing decay. Then comes a period, earlier in the case of suppressed than of dominant trees, at which the progress of the fungus can no longer be held in check and the trees become subject to severe decay, with the accompanying high percentage of cull. In other words, the decay becomes extensive. This period occurs in the age class of 161 to 200 years in the suppressed group and in the age class of 201 to 240 years in the dominant group. An analysis of the individual trees, in a table which is too long to present here, reveals the fact that this change begins at 167 years in the suppressed and at 214 years in the dominant trees.

At these ages extensive decay, as represented by severe cull cases, becomes common in the individuals of the respective groups. These ages, using Meinecke's nomenclature, may be termed the "critical age" and "age of decline" for incense cedar—that is, the ages at which suppressed trees and dominant trees, respectively, become subject to extensive decay. Meinecke found a combination of severe wounding and pronounced suppression both contributing to the critical age in white fir, but in incense cedar wounding is not necessarily a factor. This will be brought out later when mechanical injuries are considered.

After the age of decline is passed, as shown by the percentage of cull in the classes older than 240 years, the dry-rot is more extensive in the dominant than in the suppressed trees. This means that while the dominant trees are able to ward off the extensive development of the dry-rot fungus for a longer period than the suppressed trees, after the age of decline is once passed dominance ceases to be a factor in resisting decay and, in reality, seems to favor it. This may be due to the fact that in the old, overmature dominant trees there is a higher percentage of food material (i. e., heartwood) for the fungus to work on in relation to the total volume than in the case of the suppressed trees. The fungus does not attack sapwood.

Let us consider what the foregoing paragraphs mean from a practical standpoint. Roughly, we may place the critical age at 165 years and the age of decline at 210 years. This does not mean that there is no loss from decay previous to these ages, or even that there are no severe cull cases; but the latter are so rare, as shown by Table IV, that they may well be regarded as exceptions. Since all but a very few of the trees on the intermediate area are suppressed, taking this area as representative for the intermediate range we can not expect trees within this range to remain free from extensive dry-rot after they have attained the age of 165 years. In the optimum range this same age may be set for suppressed trees, while dominants will remain relatively sound until the age of 210 years is reached. On the optimum areas dominant individuals comprised 36.5 per cent of the total, but on the intermediate area only 7.6 per cent.

No relation was found between diameter breast high and dry-rot. This could hardly be expected, considering that incense cedar is a tolerant species in an uneven-aged mixed stand.

In Tables II, III, and IV the comparison of the dominant and suppressed trees in their relation to the percentage of cull due to dry-rot has been emphasized to the neglect of other considerations in which the same relation might be found in both groups. In Table V many of the data given previously but separately for the dominant and suppressed groups are combined.

TABLE V.—*Combined data relating to dry-rot found in incense cedars of the combined areas.*

Age class.	Average age (years).	Number of trees (basis).	Percentage of—			
			Dry-rot volume.	Severe cull cases.	Cull cases.	Infections.
0 to 40 years.....	40	1	0	0	0	0
41 to 80 years.....	60	51	1	0	4	6
81 to 120 years.....	105	185	3	3	20	38
121 to 160 years.....	141	284	4	2	29	46
161 to 200 years.....	180	233	10	12	42	61
201 to 240 years.....	223	118	22	30	61	73
241 to 280 years.....	259	94	44	52	79	83
281 to 320 years.....	296	49	62	67	88	92
321 to 360 years.....	334	19	67	79	90	90
361 to 400 years.....	370	4	82	75	100	100
401 to 440 years.....	436	2	5	0	100	100
Combined.....	171	1,040	18	17	42	56

Table V strikingly demonstrates the cumulative risk to incense cedar from dry-rot with advancing age. Starting at 1 per cent of cull in the age class of 41 to 80 years it mounts to 67 per cent in the class of 321 to 360 years. With a very gradual increase up to 160 years it then becomes rapid. The figure of 82 per cent in the class of 361 to 400 years, even though on an insignificant basis, is not without significance when considered in relation to the general previous progression. That this figure should drop to 5 per cent in the last age class need not cause concern, since the basis is only two trees. Even though infected, a tree may escape extensive decay throughout its life. This is a rare occurrence, however. The percentage of severe cull cases closely follows the percentage of cull throughout until the last two age classes with their small bases are reached. These two sets of figures show beyond doubt the high percentage of loss through dry-rot that may be expected in overmature cedars and clearly prove that the presence of such trees in our stands of the present and the future can be nothing but an economic loss.

That the percentages of cull cases and of infections do not follow the same form as the two others just discussed was shown in previous tables, but is more clearly brought out here. The reasons for this have been touched upon. However, these two figures are of interest when compared. It is seen that with advancing age the percentage of cull cases becomes increasingly higher at a more rapid rate than does the percentage of infections, until finally in the class of 321 to 360 years the two coincide. To be more explicit, the infections gradually begin to cause more and more measurable decay, until finally every infection has resulted in a cull case, no matter how slight. In the last two age classes both cull cases and infections have reached 100 per cent; but again we are confronted by the small basis and this figure can not be accepted. There is no doubt that a tree by rare chance may escape infection throughout its life, but there is hardly

any possibility that when once infected sooner or later some cull will not result.

To make the relation just discussed even more apparent the four sets of data have been plotted in figure 2. From this, it can be seen that the form of the curves for severe cull cases and cull are the same, but differ quite markedly from the curve for infections. This shows clearly that infections alone are not the sole influence on the development of the dry-rot fungus, for if so the curves would have the same form. The slow progress of the dry-rot in the younger trees is very apparent.

The curve for the cull cases is somewhat intermediate, at first inclining toward the severe cull cases and later coinciding with the infections. The younger trees are able to retard the fungus suffi-

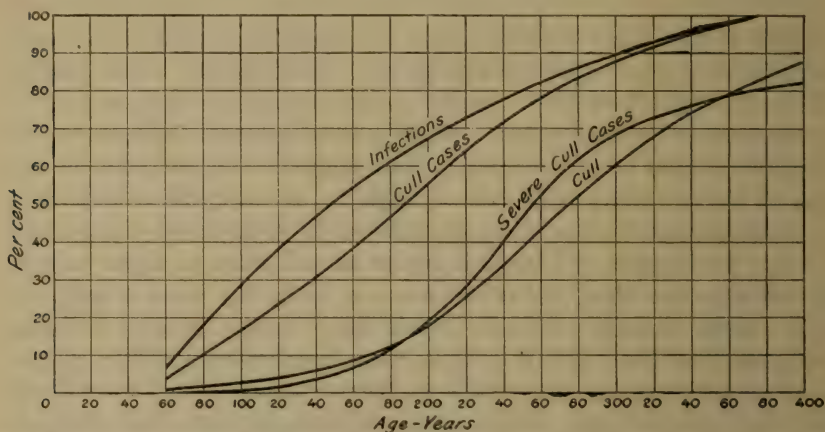


FIG. 2.—Relation of the age of incense cedar trees to infections, cull cases, severe cull cases, and cull.

ciently to prevent many of the infections from developing into cull cases, but later this characteristic is obscured.

The relative percentages of cull due to dry-rot on the various areas is not of importance from the standpoint of the present investigation. That this will vary widely even within the optimum and intermediate ranges is self-evident to anyone who has been on logging operations where incense cedar is being cut. At times the variation, even in localities quite close to each other, is surprising. On the intermediate area the cull for all the trees amounted to 20.5 per cent, while for the optimum area the figure was 16.8 per cent. These figures must not be taken as absolute, since it must be remembered that the areas were not clear cut. Practically every tree between the ages of 100 and 240 years was cut except those in which it was apparent that the age could not be accurately determined. Not all the trees below 100 years or over 240 years were cut, however, since this would have meant an enormously increased cost

without adding much to the investigation, the chief aim of which was to determine the age at which dry-rot became extensive and far-reaching. However, the relative representation of trees in the older age classes was maintained as far as possible, neglecting entirely, of course, the few very old veterans always found scattered through a virgin stand.

The cull percentages given are indicative of the relative conditions that will exist in the intermediate and optimum ranges, although stands in the latter will on the whole be relatively more free from dry-rot than our figures indicate. However, the Office of Forest Pathology is now collecting figures for cull percentage by a less intensive method over various localities, and these will include not only cull due to dry-rot but to all other causes as well.

Before drawing final conclusions there is one other factor which must be considered in relation to dry-rot, namely, wounds or mechanical injuries.

MECHANICAL INJURIES.

The mechanical injuries which must be reckoned with are those caused by fire, frost, lightning, and the breaking off of branches as well as such miscellaneous factors as snow, falling trees, mammals, and wind. These injuries are important from three standpoints. First, they often afford an entrance to the heartwood of the tree for spores of wood-destroying fungi; next, the growth processes of a tree may be somewhat interfered with, resulting in a lessening of increment and a consequent tendency to suppression; and, last and least important, an actual loss in merchantable volume may result from the mere presence of the injury.

Spores of the dry-rot fungus (*Polyporus amarus*) must have an entrance to the heartwood before they can germinate and develop. As long as the tree is protected by a layer of bark and sapwood it is immune from the ravages of dry-rot or any other heartwood destroyer. Small superficial wounds are quickly protected by resin exudation from the bark, which forms an antiseptic dressing on the wound, safeguarding it from fungous spores until the wound is finally healed or callused over. But incense cedar is poorly supplied with resin. Normally it is found in a limited quantity in the bark only, active in the inner bark, dry and hard in the outer bark. Large superficial wounds may often prove to be serious. If the bark is torn off over a large surface there is not enough resin available to form a dressing, the sapwood dries out and cracks into the heartwood, and these cracks offer an entrance for fungous spores. The most serious type of wounds, of course, are those extending deep into the heartwood, for then the heartwood is directly exposed to infection by wood-destroying fungi for the entire period of time

from the occurrence of the injury until it is completely healed over, and such injuries heal slowly. Wounds heal much more rapidly in young than in mature or overmature trees.

The causes of wounds are taken up in the order of their importance.

FIRE.

The most serious wounds, both numerically and in regard to the type of injury, result from fire. It is almost impossible to find a stand of timber anywhere in the Sierra Nevada or Coast Ranges which has not been visited by repeated fires. While the thick bark characteristic of incense cedar combined with the lack of resin in the wood makes it somewhat fire resistant, yet broad fire wounds commencing at ground level, reaching some distance up the trunk, and extending deeply into the heartwood are very frequent. These wounds are usually roughly triangular in shape, the base being at ground level and the apex at the top of the extent of the scar on the tree trunk. Considerable loss in merchantable timber results from the actual destruction of the wood, and there must be an appreciable decrease in increment until the tree readjusts itself to the loss in conducting tissue caused by the partial destruction of the sapwood and inner bark, which interferes with the conduction of water and soluble salts from the roots to the foliage and the return of elaborated food from the foliage to the roots. This loss is exceedingly difficult to gauge. Total loss in the merchantable timber occurs when a tree is completely girdled and killed or when the supporting tissue is so weakened by the wound that the tree is blown down.

Large fire scars or "catfaces" are rarely caused by only one fire, but usually by successive fires, each one hollowing out the heartwood a little more. As many as 10 distinct fires have been found contributing to the formation of one catface. As long as the wood is completely covered by a charred surface the danger of inoculation by fungous spores is reduced to the minimum, but the wood dries out and checks, forming cracks extending into the unburned wood. In time, the charred surface is weathered away, and finally the heartwood is exposed over the greater surface of the catface. Here is offered an excellent place for the entrance of a heartwood-destroying fungus.

Wounded trees make strong efforts to callus over the injury, and this is often accomplished in course of time if the wound is not too large. Very large catfaces, particularly on mature or overmature trees, are rarely healed over. The prevalence of wounds caused by fire may be seen from Table VI.

Table VI clearly shows that fire injury was much more serious on the intermediate area than on the optimum area. The columns of greatest interest are the third and last. The third column (per-

centage with open fire scars) shows that of the total number of trees analyzed on the intermediate area, 38.3 per cent had open fire scars, while on the optimum area the percentage is only 23.5. In other words, these percentages of the total number of trees cut on the areas under consideration were still exposed to infection by wood-destroying fungi through fire scars alone. The last column indicates that 72.2 per cent of the trees on the intermediate area and 49.3 per cent of those on the optimum area have had open fire scars at some period of their life history, thus exposing them to inoculation by fungous spores.

TABLE VI.—*Incense-cedar trees found in the combined areas having fire scars.*

Locality.	Number of trees (basis).	Trees with fire scars (per cent).			
		Open.	Internal.	Miscellaneous. ¹	Total.
Intermediate area.....	509	38.3	33.2	0.8	72.2
Optimum area.....	566	23.5	25.4	.4	49.3
Combined.....	1,075	30.5	29.1	.5	60.1

¹ Includes wounds probably but not certainly caused by fire.

The internal scars on the intermediate area exceeded those on the optimum area by less than 8 per cent, but there were 15 per cent more open scars. This points to the fact that the intermediate area has been visited by more serious fires than the other, since, as has already been pointed out, large catfaces are normally the result of repeated fires.

The combined figures for all the areas show that a total of 30.5 per cent of the trees had open fire scars, while 60 per cent suffered fire injury at some time. The column headed "Miscellaneous" includes trees with scars not identified beyond all doubt as having been caused by fire. These are so few that they need not enter into the interpretation of the figures.

FROST.

Frost causes some injury in incense cedar but is not nearly as serious in this respect as fire. Frost cracks as a rule extend for some distance up the tree and go deeply into the heartwood. A common place for the cracks to commence is just at the apex of an open fire scar, apparently a point of weakness in the tissues of the wood. Often they are somewhat spirally twisted around the trunk, distinctly reminding one of typical lightning scars. While frost cracks present only a very narrow opening for the entrance of fungous spores, yet in length those cracks or clefts are often quite extensive. In many cases the wood around a frost crack is badly discolored, causing considerable loss in the merchantable contents of the tree.

Typical frost cracks are rarely found except on large trees. Table VII shows the percentage of frost cracks on the trees analyzed.

TABLE VII.—*Incense-cedar trees found in the combined areas having frost cracks.*

Locality.	Number of trees (basis).	Trees with frost cracks (per cent).		
		Open.	Internal.	Total.
Intermediate area.....	509	4.12	3.14	7.26
Optimum area.....	566	1.41	.53	1.94
Combined.....	1,075	2.70	1.77	4.47

Here again, as in the case of fire, the wounding is worse on the intermediate than on the optimum area. The percentage of trees exposed now or in the past to inoculation by fungous spores through the medium of frost cracks is rather low and not of great importance on any of the areas. Frost cracks in incense cedar are not nearly so prevalent as Meinecke (16, p. 31) found for white fir.

LIGHTNING.

Incense cedar suffers only slightly from injury by lightning. This is to be expected, since the dominant species in a stand and as such the taller trees (25, p. 36) are most subject to lightning stroke, while incense cedar rarely attains this position in the mixed stand in which it is found. Plummer (25, p. 33) also shows that incense-cedar wood is a poor conductor of electricity.

An incense-cedar tree in the forest badly shattered by lightning is an exceedingly rare sight and immediately provokes comment. However, trees with slight lightning injuries are more common. Such injuries show as superficial wounds on the trunk. Often the wood is not scarred, but the bark and cambium are killed. The bark then drops away, exposing the sapwood, which in turn dries out and checks, offering fungous spores access to the heartwood. Long wounds extending spirally around the tree, so common in white and red fir in this region, are an unusual occurrence on incense cedar.

Table VIII indicates the prevalence of lightning scars.

TABLE VIII.—*Incense-cedar trees found on the combined areas having lightning scars.*

Locality.	Number of trees (basis).	Trees with lightning scars (per cent).		
		Open.	Internal.	Total.
Intermediate area.....	509	1.76	2.53	4.31
Optimum area.....	566	3.54	1.06	4.60
Combined.....	1,075	2.70	1.77	4.47

Besides the trees shown in Table VIII, there were seven on the intermediate area and five on the optimum area with slight wounds which appeared to have resulted from lightning; but an absolute determination was impossible. The meager basis in this table shows practically an equal number of lightning-scarred trees in the two localities.

BREAKING BRANCHES.

Incense cedar does not prune itself easily even when growing in a dense stand, a fact attested by the persistence of the lower limbs. In time, however, some of the lower branches die and break off. The dead stubs then offer a point of entrance for heartwood-destroying fungi; the spores lodging in the dead wood may germinate, develop, and the fungous hyphæ pass through the bark and sapwood of the tree into the heartwood by way of the pin knot. The pin knot in this case plays exactly the same rôle as an open wound, but it must be remembered that the area for lodgment of a fungous spore on a pin knot that is not healed over is exceedingly small in comparison with other types of wounds. On the other hand, there are normally from several to many open pin knots on each tree, and every tree, throughout all but the earliest years of its life, is thus exposed to inoculation by fungous spores through these open pin knots. Many of course heal over, but others take their places.

OTHER CAUSES.

Besides the causes of wounds already discussed, there are a few others of minor importance.

Strong winds will occasionally break off branches or tops, or overthrow entire trees, particularly those weakened by a bad open fire scar in the butt. The thick foliage of incense cedar collects a very heavy weight of wet snow, often causing the tops and branches of young trees especially to break off. Sometimes a falling tree will rake off the limbs and part of the bark of a neighbor. Such injuries are usually superficial unless very large branches have been broken off or the bark has been torn away from the trunk over a considerable area.

Man is at times directly responsible for certain wounds. It is quite a common sight along a newly constructed road to see bark torn off, often rather high on the trunk, where the tree has been struck by a flying rock from a powder blast. Some wounds result from blazing trees to mark a boundary line or trail, but they are usually small and rapidly heal over.

Broken or dead tops, the cause of which is often impossible to determine, are not at all rare. Trees with these injuries comprised 6.9 per cent of the total number on the intermediate area and 7.1 per cent on the optimum area.

PREVALENCE OF INJURIES.

Most incense cedars do not attain any great age or size without suffering some injury. Many old trees, and more rarely young ones, show numerous injuries, often fire, frost, and lightning having combined in the wounding of a single tree. Of the 509 trees on the intermediate area only 116, or 22.8 per cent, escaped without injury, while on the optimum area 38.9 per cent, or 220 of the total 566, were free from wounds. This difference is explained by the fact that the risk from injury has been greater on the intermediate area than on the optimum area, while a greater number of young trees were cut on the last-named area than on the first. The risk of injury is cumulative, increasing with the age of the tree.

This cumulative risk of wounding is shown clearly in Table IX, in which the trees from all areas are combined and arranged by 40-year age classes. Only those trees the ages of which it was possible to determine exactly are included in this table, while the data on wounds previously presented include all the trees. This accounts for the apparent slight discrepancy between the figures on the total number of trees involved.

TABLE IX.—*Incense-cedar trees showing cumulative wounding in the combined areas.*

Age class.	Number of trees (basis).	Total with wounds (per cent).	Trees with severe wounds (percent-age of total wounds).	Age class.	Number of trees (basis).	Total with wounds (per cent).	Trees with severe wounds (percent-age of total wounds).
1	2	3	4	1	2	3	4
0 to 40 years.....	1	0	0	281 to 320 years.....	49	98	62.5
41 to 80 years.....	51	29.4	6.7	321 to 360 years.....	19	100	68.5
81 to 120 years.....	185	48.6	14.4	361 to 400 years.....	4	100	100
121 to 160 years.....	284	59.2	28.6	401 to 440 years.....	2	100	50
161 to 200 years.....	233	74.3	35.2				
201 to 240 years.....	118	82.2	44.4	Combined....	1,040	67.6	36.3
241 to 280 years.....	94	92.6	43.6				

In considering the figures in Table IX the reader should keep in mind the fact that since branch stubs are not treated as wounds, wounded trees practically mean fire-scarred trees, as the number of wounds from causes other than fire have been shown to be insignificant.

Considering column 3, which expresses the ratio of the wounded trees to the total trees, it is seen that the trees are subject to considerable wounding at a very early age and that this percentage increases very rapidly, until in the older age classes every tree has been wounded and consequently at some time exposed to infection.

Not only does the total number of wounds increase with age in a stand, but the number of severe wounds becomes proportionately greater. Each tree was given a wound rating (x), x, xx, or xxx, the first symbol indicating very slight wounding and the last very severe. In Table IX trees with a rating of xx or xxx are considered as severely wounded. In all cases the character as well as the extent of the wounding and its relation to inoculation by spores of the dry-rot fungus was carefully taken into account in applying the rating.

In column 4 of Table IX it is seen that while in the age class of 41 to 80 years only 6.7 per cent of the wounded trees are severely wounded, an almost steady increase brings this figure to 68.5 per cent in the class of 321 to 360 years. This is to be expected, especially since fire scars predominate, because large scars of this type are almost invariably the result of recurring fires, and in the past virgin stands in California have been fire swept time and again. The two oldest age classes can not be given much weight, owing to an insignificant basis.

The above figures demonstrate the rather slight chance an incense cedar has of rounding out its life without a reduction in its normal increment through an injury interfering with the growth processes or a reduction in its actual content of merchantable timber, either directly from a wound or by a wound affording an entrance for a heartwood-destroying fungus, in this instance most probably the dry-rot fungus (*Polyporus amarus*).

RELATION OF DRY-ROT TO MECHANICAL INJURIES.

The intimate connection of various kinds of wounding, especially fire, with infection by the dry-rot are shown in Table X. The infections are grouped under their respective causes and percentages for each cause, figured on the basis of the total number of infections. Trees of uncertain ages are included in these figures, since it makes no difference in this table whether or not the absolute age of the tree is known.

TABLE X.—Mode of entrance of dry-rot infections of incense-cedar trees.

Locality.	Number of infections (basis).	Means of entrance of infections (per cent).						
		Fire scars.	Knots.	Wounds, cause unknown.	Lightning scars.	Unknown causes.	Frost cracks.	Broken or dead tops.
Intermediate area.....	*322	75.8	19.3	0.6	2.5	0.9	0.6	0.3
Optimum area.....	334	58.7	31.1	5.1	1.5	2.4	.9	.3
Combined.....	656	67.1	25.3	2.9	2.0	1.7	.8	.3

Table X shows that on the intermediate area nearly 76 per cent of all the infections entered through fire wounds; this means of entrance for the optimum area is approximately 59 per cent, while for all the areas combined it is almost 70 per cent. Since fire scars are almost invariably found in the base of the tree, commencing at ground level, these figures are at variance with Von Schrenk's (26, p. 69) idea that "the decay begins somewhere in the upper part of a tree."

Besides fire wounds being responsible for such a high percentage of the infections, inoculations through wounds of this character quite commonly lead to very serious and damaging dry-rot, even in some of the younger trees. In many cases, even in old trees, a long continuous pocket of dry-rot, sometimes having a linear extent of 10 feet, will follow a healed fire scar, running out at the end of the wound, with no further decay extending up the tree. Such infections do not appear especially serious, but it must be remembered that the most valuable portion of the trees, the heartwood in the butt log, is damaged. On the other hand, the fungus evidently finds conditions highly unsuitable in the wood back of a large open fire scar. Almost every tree with this type of wound appeared sound on the stump when felled, but serious dry-rot appeared at the first cut above the open fire scar. When such logs were split, it was found that the pockets of dry-rot commenced just at or a little above the top of the open fire scar, but rarely lower down. The avoidance of the dried-out wood around an open fire scar by the mycelium of this fungus is not at all in keeping with the results of experiments of Münch (19, 20, 21), which emphasized the highly favorable influence of an increase in oxygen coupled with a decrease in moisture in the host tissues on the development of various wood-inhabiting fungi. There should certainly be a big increase in the oxygen content of heartwood directly exposed to the air over that protected by a heavy layer of bark and sapwood, thus, according to Münch's theory, causing very serious dry-rot in the wood around open fire scars. The exact reverse of this is the condition actually existing. However, every wood-inhabiting fungus must have certain minimum physical requirements for its growth and development. Possibly the dried-out wood in this case falls below the minimum water requirement of *Polyporus amarus*, or it may be that certain chemical changes in the wood brought about by more or less exposure to the air inhibit the growth of the fungus mycelium.

Not every fire scar is inoculated, but the chances for inoculation with subsequent infection are rather high, owing to the relatively large area of heartwood exposed offering a broad surface for the lodgment of spores of the dry-rot fungus. On the optimum area, 70 per cent of the trees wounded by fire subsequently became infected,

on the intermediate area 64 per cent, and on the combined areas 67 per cent. The percentage of risk of a tree with a fire scar becoming infected is very high.

Next in importance to fire scars as a means of entrance for dry-rot come knots. Of the infections on the intermediate area 19 per cent entered in this way and 31 per cent on the optimum area, while for the areas combined the figure is 25 per cent, a little more than one-third as many as were traced to fire scars. The greater part of such infections, because they rarely extend beyond the wood of the knot itself, are of little or no importance as compared with fire scars in promoting serious cull. Of the total infections entering through knots only 48 per cent resulted in cull cases and 12 per cent in severe cull cases, while in infections through fire scars, 80 per cent of the total became cull cases and 38 per cent severe cull cases. The above data were at first tabulated by 40-year age classes, but this brought out nothing of importance. In the case of infections through fire scars most of them developed into cull cases in every age class; while for infections through knots up to 200 years less than half developed into cull cases, but beyond that age the cull cases became more numerous.

Considering all the severe cull cases as 100 per cent, it is found that fire is responsible for 84 per cent, knots for 10 per cent, and all other causes for the remaining 6 per cent. Furthermore, 81 per cent of the total volume of cull caused by dry-rot resulted from infections entering through fire scars. This demonstrates the serious rôle played by fire in connection with dry-rot. Fire scars are responsible for by far the greater number of infections, and a high percentage of these infections results in severe cull cases.

Knots are of some importance, though, in promoting severe cull cases throughout the life of the trees, even in the younger age classes. For example, of the fourteen severe cull cases occurring in all the trees up to 165 years of age, four entered through knots.

Of course, every tree is exposed to infection in this way throughout all except the very earliest years of its life, not only at one but at several points, since each tree usually has from several to many open knots or branch stubs, whose dead wood offers a bridge for the fungus from the outside through the bark and living sapwood into the heartwood. However, each knot presents only a very small surface for the lodgment of spores of heartwood-destroying fungi. Out of the total number of trees open to inoculation through knots on the optimum area only 18.2 per cent became infected in this way, on the intermediate area only 11.4 per cent, and for all combined just 15 per cent. In other words, in the trees studied the chances for a tree becoming infected with dry-rot through branch stubs were merely 15 out of 100.

An examination of knots on the outside of a log or tree usually does not give any reliable indication of the condition of the heartwood with respect to its degree of soundness. In this respect dry-rot differs markedly from the stringy brown-rot (*Echinodontium tinctorium*) in white fir and the ring scale or red-rot (*Trametes pini*) in Douglas fir.

Fire and knots are responsible for over 90 per cent of the infections and severe cull cases; other factors are of minor importance.

About 3 per cent of the infections on the combined areas entered through wounds the causes of which it was impossible to exactly determine. Some of these may have been fire wounds, others lightning. Of all such wounds 23 per cent subsequently became infected.

Lightning is of little importance as a means of entrance for dry-rot. On the intermediate area only 2.5 per cent of the infections are traced to this source, on the optimum area 1.5 per cent, and for the combined areas 2 per cent. As a rule, lightning causes small superficial scars offering little opportunity for inoculation, but at times large areas of the cambium and bark are killed. This dead bark then drops off, exposing the sapwood, which dries out. Cracks opening up into the heartwood are formed, and such large areas offer a good chance for the lodgment of fungous spores. This condition is reflected in the percentage of risk of inoculation when it is found that 19.2 per cent of the lightning-struck trees on the optimum area, 31.8 per cent on the intermediate area, and 25 per cent for the combined areas were infected by dry-rot through lightning wounds. This figure is higher than that for all other factors except fire. The chief reason, then, that lightning wounds are of so little importance in relation to decay is not that the character of wounding on the whole is such as to offer little opportunity for inoculation, but rather that this type of wounding is rare.

As an actual means of entrance of decay, frost cracks are even less important than lightning wounds. These cracks, while often of considerable length, even then present only a very narrow opening exposed to the air, the chances of fungous spores lodging in such a small opening being exceedingly small. Not quite 1 per cent of the infections for the combined areas entered through frost cracks, while the risk of infection is only 10.4 per cent lower than for all others except broken and dead tops. But though a rare source of infection, frost cracks sometimes carry an infection, entering through some other type of wound, over a greater linear extent in the heartwood than might normally be expected, thus resulting in a large proportion of cull. The pockets of dry-rot do not occur in the wood immediately adjacent to the cleft or crack, but are usually found some distance removed, leaving the wood around the crack sound.

This is because of the avoidance by the fungus mycelium of the wood around open fire scars.

Infections through broken or dead tops may be absolutely disregarded, both numerically and in respect to the resulting decay. Out of the 75 trees with these injuries only one infection occurred, and this resulted in a negligible amount of decay.

However, the true relation of these various types of mechanical injuries to one another in respect to their importance as a means for the entrance and development of dry-rot on the areas studied is not expressed by the percentage of the total infections for which each type of injury is responsible, but must be shown by the relation of the number of trees infected through each type of wound to the total number of trees both sound and infected. The figures in Table XI express this relation, which might be termed "percentage of risk of infection." In one set of figures is expressed, then, for the trees actually studied the numerical relation of the various types of injuries combined with the relative chances for inoculation offered by each. All the areas are combined.

TABLE XI.—*Risk of infection of incense-cedar trees with dry-rot entering through wounds of the various types.*

Cause of wounding.	Risk of infection (per cent).	Cause of wounding.	Risk of infection (per cent).
Fire.....	40.0	Lightning.....	1.2
Knots.....	15.8	Frost.....	.5
Unknown.....	1.6	Broken or dead tops.....	.1

The figure 40 for fire expresses the fact that of all the trees analyzed each tree had 40 chances out of 100 of being wounded by fire and subsequently becoming infected with dry-rot through this wound, and so on for the other types of injury.

The far greater importance of fire wounds as a means of entrance for dry-rot as compared with all other injuries is strikingly brought out. Knots, the nearest competitor, are far less important, while all the others practically can be neglected.

The close relation of wounds and infections is shown even better in figure 3. The curve for wounds is plotted from Table IX, knots, of course, not being included, for had this been done the wound curve would have followed the 100 per cent ordinate throughout all the ages. The curves for infections and cull are the same as those given in figure 2.

These curves show that infections are practically a function of wounds, the two curves having almost the same form, but of course the infection curve being lower throughout until both have attained 100 per cent. The curve for the percentage of cull is included in

order to emphasize the fact that while the increase in the number of wounds is closely followed by an increase in infections, the increase in the amount of cull due to decay is not a direct function of the increase in infections, but is also dependent upon the factor of age and thrift, as previously explained.

Meinecke (16, pp. 47-48) found in white fir that a combination of suppression and severe wounding was a prerequisite for serious decay in trees up to the age of 150 years. This does not hold for incense cedar. Of the ten severe cull cases in suppressed trees up to the age of 165 years, five occurred in trees slightly wounded, one in an entirely unwounded individual, and only four on severely wounded trees. Of the four dominant trees below the same age with severe cull cases, two are severely wounded and two slightly

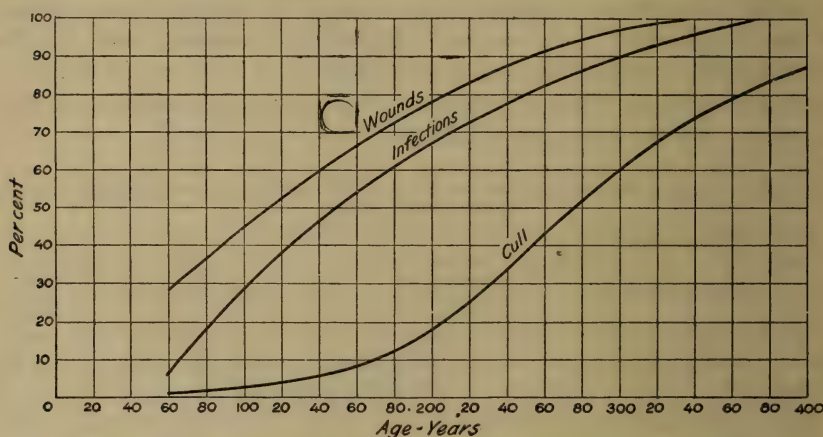


FIG. 3.—Relation of the age of incense-cedar trees to wounds, infections, and cull.

wounded. And, in fact, throughout all the age classes occur trees slightly wounded but with severe cull cases.

The foregoing considerations lead to the following conclusions: (1) Fire is responsible for by far the greatest number of dry-rot infections, commonly leading to serious decay, resulting in heavy cull. Fire is three times as important as its closest competitor, knots. (2) Knots are responsible for some far-reaching decay, but most of the infections through knots are confined to the immediate vicinity of the knot. (3) Aside from fire and knots all other means of entrance for decay are of little import. Lightning would be serious except that wounding from this source is rare. Frost is of no importance in promoting inoculation, since the wounded surface presented is small and frost cracks are relatively few. However, frost cracks often assist in carrying the dry-rot over a greater length of the bole than would be normal. Damage from unknown causes leads to some infection, but it is not of much importance. Infections

through dead or broken tops are so insignificant that they may be entirely disregarded. (4) Severe wounding is not a prerequisite for severe cull cases or extensive decay at any stage in the life of incense cedar.

APPLICATION OF RESULTS.

RELATIVE IMPORTANCE OF DRY-ROT.

In the foregoing discussion the one big factor which stands out almost to the exclusion of all others is the dry-rot. Mechanical injuries of certain types play some rôle, not only in destroying merchantable timber values but in lessening the annual increment. However, it is chiefly the fact that wounds are the means for the entrance of dry-rot which makes them of any but insignificant importance.

Factors reducing the annual increment of the host, namely, *Gymnosporangium blasdaleanum*, *Phoradendron juniperinum libocedri*, *Stigmatea sequoiae*, and *Herpotrichia nigra* are of minor importance. In fact, only the first two named, being decidedly ubiquitous, are worthy of the least consideration; but the resulting loss is so slight and intangible that under present conditions it may well be disregarded except incidentally. The rare trifling loss in merchantable timber from burls of the mistletoe can not be of consequence.

Fungi such as *Polystictus abietinus*, *P. versicolor*, *Polyporus volvatus*, and others (see p. 4), only attacking dead wood and never found on living trees, are to be regarded as beneficial, since they hasten the decomposition of ground litter, thus increasing the humus in the soil and removing a serious fire menace.

Loss resulting in the heartwood of living trees from the so-called secondary rots is very slight in the aggregate. It is rare that such decays are at all far-reaching, and, furthermore, it is possible that certain of them may be abnormal forms of the dry-rot.

To repeat, then, the one big consideration from a pathological viewpoint which must hold above all in the silvicultural treatment and utilization of incense cedar is the dry-rot, together with the interrelated mechanical injuries.

CONTROL OF DRY-ROT.

Very little can be hoped for in the line of any serious consideration or attempt at direct control of dry-rot on private holdings for years to come. The private owner is averse to any increase in expenditures which does not show prospects of immediate gain. On certain private holdings where the incense cedar was heavily affected by dry-rot, all the trees have been left standing, only the more valuable species being removed, leaving the diseased individuals to continue spreading the decay to uninfected members of the present and future generations.

On the National Forests a great deal can be accomplished in the way of control of mechanical injuries resulting in wounds through which the dry-rot fungus can enter. As has been shown, fire is by far the most important factor in promoting dry-rot, with knots, the nearest competitor, of relatively far less importance both in regard to the number and seriousness of resulting infections.

Fire can be, in a great measure, directly controlled. The ever-increasing efficiency of the fire-protection methods on the National Forests, with the continual reduction in the number of damaging fires, speaks for itself. Certain private holdings are also protected from fire, either incidentally by falling within the boundaries of a National Forest or through a protection system handled on a cooperative basis by the United States Forest Service. Knots, of course, can not be controlled. Natural pruning, with the continual production of dead branches, which later break off, is inevitable in any forest. However, it may be expected that infections through this source will become increasingly fewer as time goes on, in proportion to the reduction in the number of fire-wounded trees. All other factors, whether controllable or uncontrollable, and this includes frost and lightning, are of so little importance that they may be neglected in any consideration of mechanical injuries in the future stand.

But fire protection works for the future welfare of the stand alone. It can not affect the huge number of individuals in the forest with healed or open wounds through which dry-rot has already entered or those uninfected individuals with open wounds still exposing them to attack by heartwood-destroying fungi; nor can it have any influence on all the other injured, diseased, or distorted members of the forest community. These have no place in the stand, are in most cases a direct menace to the sound trees, and should be removed as soon as possible. Unfortunately, we have not been able to attain the highly desirable intensive practice of eradicating such undesirable individuals by means of improvement thinnings applied at will wherever needed in the forest.

Under present conditions this can only be done in the main through timber sales, with free-use permits playing a limited part. But the Government is far from able to sell the timber where cutting is most needed from a silvicultural point of view. Economic factors, especially transportation, and in some cases the degree of soundness of the stand play the chief rôle in determining the exact location of a sale area. In fact, a mature or overmature stand badly in need of cutting may have to be left untouched, owing to the refusal of prospective purchasers to handle the high representation of inferior species.

In the case of incense cedar, this prejudice on the part of the lumberman does not arise from any inherent qualities or characteristics

of the timber itself, but from the heavy infection of dry-rot in the mature and overmature trees, with the resulting high percentage of cull. Sound incense cedar is distinctly of high value and much sought after for special purposes, such as pencil slats, and in a lesser degree for cabinet material and interior finish. Wood not too badly decayed is of some value for posts and low-grade railroad ties. But the lumberman is naturally averse to handling a large quantity of unmerchantable material in order to secure a small percentage of a really valuable product.

The first step in overcoming this objection must be the application of a careful scaling policy.

SCALING.

In order to handle incense cedar properly on a timber sale the outward indications of hidden defect should be thoroughly understood. A valuable index to the condition of the timber will be found in the presence of sporophores or shot-hole cups on the trees. When found, their apparent age should be carefully taken into account in determining the degree and extent of the dry-rot (see p. 10). Excellent clues as to how a decayed tree should best be bucked are contained in the occurrence of shot-hole cups or sporophores. Since heavy dry-rot almost invariably extends from the ground level to a varying height above the highest sporophore or shot-hole cup it would, of course, be a waste of labor to buck the tree again at any place between the stump height and the last-named point.

The scaler should keep in mind the relation of wounds, particularly those caused by fire, to dry-rot in the tree. A large pocket of dry-rot occurring close to a healed wound, especially fire scars in the butt of the tree, usually diminishes in area as the height increases and ends in a point immediately above the termination of the healed fire scar it is following. For example, in case a butt log shows a large pocket of decay adjacent to a healed fire scar on its basal cross section, while the top cross section is absolutely sound, it is safe to assume that the decay will end about 6 feet from the base of the log, or in exceptional cases a length of 10 feet may be attained (see p. 44).

Particular care should be used in scaling butt logs with an open fire scar at the base. As has been shown (see p. 44), dry-rot of any seriousness is rarely found in the dried-out wood around an open fire scar. The base of such a log is nearly always absolutely sound; the top may show the entire heartwood unmerchantable. It is quite possible, then, for the scaler to judge the decay as extending half way down the log from the top, giving the lower half full scale and judging the upper half unmerchantable. This procedure is

particularly likely to be followed on double-length logs (20, 24, 28 feet, etc.). But invariably the dry-rot will commence just at the top of the fire scar and almost immediately spreads out over the entire radius of the heartwood. In other words, in a log with an open fire scar showing on the base but otherwise sound and with pockets of dry-rot in the top end, the decay should be considered as beginning at about the top of the fire scar and extending from there to the upper end of the log in practically the same degree and radial extent with relation to the heartwood as is shown on the top end.

Advance rot (see p. 13) should be treated just the same as mature dry-rot.

In the case of a large swelling on the bole caused by mistletoe it is best to have the tree bucked in such a manner as to exclude the swelling rather than have such a defect reach the landing as part of an otherwise sound log and then be scaled out.

MARKING.

Timber sales at present offer the only extensive means of practicing intensive silviculture on our National Forests, and the entire results are absolutely based on correct marking. Fundamentally, the object of marking is to leave the stand in the optimum condition for its future welfare and development. This goal should never be lost sight of, no matter how clouded the issue may be by a complexity of immediate and often pressing considerations. To attain this end requires a high degree of skill, grounded on a thorough understanding of all the factors involved, not the least of which are those making for total loss in the species under consideration.

The fundamental object of marking has been far from completely attained if, after cutting, diseased individuals are left standing to carry infection to otherwise sound trees of merchantable size, besides menacing the future of the advance growth and reproduction. Obviously, then, trees with sporophores or shot-hole cups should invariably be marked for cutting, for these are positive proofs of damaging dry-rot. Such trees are as a rule not only a total loss, being unmerchantable from the butt to varying distances of 10 to 50 feet above the highest sporophore or shot-hole cup, but are the most potent factors in spreading infection to other trees, since infection can only be brought about by spores coming from sporophores on diseased trees. True enough, shot-hole cups in themselves do not menace surrounding trees with possible infection, but they do indicate that the fungus has reached fruiting maturity and is very likely to develop more sporophores, as is attested by the not uncommon occurrence of two or more shot-hole cups of varying ages on the same tree. Furthermore, the fungus mycelium in any in-

fectured tree possesses the potential capacity of sooner or later producing sporophores.

Remembering the great percentage of dry-rot infections entering through wounds, trees with injuries must be treated accordingly. Trees with healed wounds are of less concern than those with open wounds, since the former, if not already infected, are immune except for the inevitable, though fortunately not frequent, attack through branch stubs, while the latter are still open to infection. Then, too, the area of heartwood exposed by the injury is of grave consequence; the larger the area the greater the opportunity for infection. We already know the high percentage of infections through fire scars which so commonly expose large areas of heartwood; therefore fire-scarred trees, above all, should be marked as heavily as possible. Large lightning wounds are a serious danger, but small superficial injuries, especially if high up on the bole, can be almost disregarded. Frost cracks, though by virtue of the exceedingly small amount of heartwood they expose offering slight chance for infection, often aid in spreading infection established through some other agency, and trees with such wounds should be marked for cutting whenever possible. From the pathological viewpoint spiketops or stagheads may be almost disregarded except for their suppressing influence on the injured individual, but sound silviculture demands the removal of such trees from the stand.

Even if the Utopian dream of a forest community without injured individuals could be attained, this in itself would not result in completely controlling the destruction wrought by the dry-rot fungus, but only in minimizing it in a great measure. There would still be some loss from infections entering through knots. Then, too, no matter to what degree of intensive management a forest in this region may be brought in the future, some injuries will always occur, even from fire, while frost and lightning wounds are inevitable. The unavoidable injuries to a certain number of the seed trees during logging on any sales area must not be overlooked.

Therefore, all wounded trees must not only be eliminated on sales areas, but trees, even though unwounded and thrifty, must not be left with the expectation that they will be sound at the next cutting if by the time the cutting takes place they will have attained or passed beyond the age at which loss from dry-rot becomes of serious economic importance. It has been shown that the critical age occurs at 165 years and the age of decline at 210 years. Beyond the age of 165 years suppressed trees become subject to extensive decay, while up to that age they may be expected, with rare exceptions, to remain relatively sound, the same being true for the dominant trees at an age of 210 years.

Since in the intermediate range all but an insignificant percentage of the trees are suppressed in a greater or less degree, it becomes obvious that in this region incense cedar should be cut by the time it reaches 165 years, the critical age.

In the optimum range, suppressed trees must not be allowed to pass 165 years and dominant individuals 210 years (the age of decline) before felling.

Even in the distant future, when the risk of wounding in the forests is reduced to a minimum, it is highly problematical whether a new age of decline can be established at a higher age, on account of the entrance of decay through knots. Damaging dry-rot has entered trees through knots beginning at 105 years, and while such cases are rare in the years below the critical age and age of decline, yet they are sufficient to indicate that this condition will always have to be reckoned with. Furthermore, as time goes on, the increasing value of timber will result in noticeably lowering figures as to what constitutes an allowable percentage of cull in any species.

From a pathological viewpoint the critical age must limit the rotation of incense cedar in the intermediate range. It is doubtful whether even in the managed stands of the future the incense cedars in this range will be other than suppressed in most cases, since the present widespread suppression does not seem to be the result of any influence that could be removed by a system of forest management, arising apparently from the fact that the cedar is removed from the region of its optimum development.

In the optimum range the rotation must be limited by the age of decline. The critical age is not so important except during the period of transition, for suppressed trees, while common enough in the virgin stands of to-day in this range, will have little place in the managed stands of the future. Here, the species being in its optimum, nothing but thrifty, dominant individuals should be produced under a rational system of management.

The influence of decay on harvesting a timber crop was hinted at years ago by Von Schrenk (27, p. 203) and clearly pointed out by Meinecke (16, p. 61) for white fir. Mitchell (17, p. 32) took this so-called pathological rotation carefully into account, recommending a rotation of 150 years, at which time the species attains a good merchantable size. The rotation recommended by Mitchell is based on Meinecke's preliminary study of dry-rot.

As a result of the present study, the pathological rotation for incense cedar must be placed at 165 years in the intermediate and 210 years in the optimum range. During the transition period, while suppressed trees are still a factor in the optimum range, these should be cut when not older than 165 years. This does not mean that in the two regions under consideration cedar can best be cut at regular

intervals of 165 and 210 years, respectively, but simply that if it is left to a greater age there is a full realization of the resulting enormously increased loss through dry-rot. The pathological rotation becomes a maximum limiting factor for the actual rotation, which may be financial, silvicultural, or one of maximum volume, depending on conditions in the future. From present indications it is highly probable that all other rotations for incense cedar will fall below the pathological rotation in both regions; the difference will be quite marked in the optimum range. It is possible in the optimum range that during the transition period, if necessary to leave suppressed trees standing after cutting, the increased vigor of such individuals which may follow the opening up of the stand might raise the critical age somewhat, but in the present state of our knowledge not only regarding the influence of thinning on the development of wood-destroying fungi in standing trees, but in the case of incense cedar regarding the actual response of the trees themselves, this consideration is entirely too hypothetical to influence our present conclusions.

SUMMARY.

The results of this study point to the following main conclusions:

(1) Incense cedar is classed as an inferior species because of a uniformly heavy percentage of cull caused by the dry-rot fungus (*Polyporus amarus*). Judicious scaling and instruction in the proper methods of bucking will ultimately aid materially in changing this view.

(2) Dry-rot can be eliminated in a large measure from future stands by intensive fire protection, but it can not be entirely controlled in this way, owing to the continued occurrence of unavoidable mechanical injuries caused by pruning, lightning, and frost.

(3) The following directions should apply to marking on timber sales:

(a) Trees with sporophores and shot-hole cups must be marked for cutting.

(b) Seriously wounded trees, especially those with fire scars, should be marked to be cut.

(c) In the intermediate range all but a very small percentage of the trees are suppressed. Since suppressed trees are subject to severe dry-rot after they pass the critical age of 165 years, trees left standing should be of such an age that they will not pass that age before the next cutting occurs. Dominant trees, being so few, may be classed with suppressed trees, but in reserving seed trees only the most thrifty individuals should be considered. By this practice some dominants will be among the trees left, and these will be safe until the age of 210 years is reached.

(d) In the optimum range, suppressed trees are subject to damaging dry-rot after they pass the age of 165 years (the critical age), while dominant trees are safe until 210 years (the age of decline) is reached. Therefore, suppressed trees left standing must be of such an age that they will not pass the critical age (165 years) before the next cutting occurs, and dominant trees left should not pass the age of decline (210 years) before the next cutting. Suppressed trees, however, should be heavily marked for cutting and only left unmarked if unavoidable.

(4) The rotation for incense cedar must not exceed 165 years in the intermediate and 210 years in the optimum range.

If for any reason the pathological rotations, as determined in this paper, must be exceeded in future operations on cut-over lands, the forester in making the decision will have a full realization of the enormous loss in merchantable timber to be faced through cumulative risk of cull due to dry-rot in the stands so handled.

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PROFESSIONAL PAPER

June 16, 1921

DAMPING-OFF IN FOREST NURSERIES.

By CARL HARTLEY, formerly *Pathologist, Office of Investigations in Forest Pathology.*

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DAMPING-OFF IN GENERAL.

Damping-off is the commonest English name for a symptomatic group of diseases affecting great numbers of plant species of widely separated phylogenetic groups. It is commonly used for any disease which results in the rapid decay of young succulent seedlings or soft cuttings. Young shoots from underground rootstocks may also be damped-off before they break through the soil (66).¹ The same term is even used for diseases affecting the prothallia of vascular cryptogams (2). The name apparently originated in the fact that the disease is usually most prevalent under excessively moist conditions. In those cases in which the disease becomes serious without the presence of unusual amounts of moisture the term is a misnomer. It is, however, so thoroughly established in practical use that it would be impossible, even if desirable, to establish any other name.

¹ The serial numbers in parentheses refer to "Literature cited," at the end of this bulletin.

While the parasites reported as causing damping-off are probably not as numerous as the host species which are subject to it, a considerable number are known. Two quite different types of damping-off parasites may be recognized. In the first type we have fungi, such as *Pythium debaryanum* Hesse and *Corticium vagum* B. and C., soil inhabiting and primarily saprophytic, which attack a great variety of hosts, and are at least better known, if not more destructive, as damping-off organisms than as parasites on older plants. They are specialized as to the type and age of tissues which they attack rather than as to host. The second type includes fungi less common as saprophytes and with a relatively limited, sometimes very closely limited, host range. *Phoma betae*, the systemic parasite of sugar beet (37), is an excellent example of the host-specialized parasite, transmitted in the seed and capable of seriously injuring various parts of the older plant at different stages of growth as well as attacking seedlings.

Most damping-off parasites are intermediate in habit between the extremes of these two types. Of those which are somewhat host specialized, the following may be mentioned:

Phomopsis vexans, the cause of foot-rot of eggplant, reported by Sherbakoff (128) as a frequent cause of damping-off of this host and believed to be carried on seed.

Gibberella saubinetii (Mont.) Sacc. (29) and the imperfect fungi which kill grain seedlings as well as cause diseases of the older plants (80; 126, p. 218). Species of *Gloeosporium* and *Volutella* named by Atkinson (2, p. 269; 52) as able to kill seedlings or cuttings of particular host plants.

Glomerella (*Colletotrichum*) *gossypii*, described by Atkinson (1) and Barre (4) as likely to cause damping-off of cotton (112).

Fusarium lini, the flax parasite, reported by Bolley (14) as destructive to young seedlings.

Phoma lingam, the cause of black-leg of cabbage, at least under inoculation conditions able to kill quickly seedlings of cabbage and other crucifers (72).

Peronospora parasitica (Pers.) De Bary, a downy mildew attacking cabbage and various other crucifers, reported as killing thousands of very young cabbage plants in Florida seed beds (41).

The entomophthoraceous *Completozia complens*, on fern prothallia (1; 87, p. 203).

Bacillus malvacearum, a parasite of the leaves of cotton plants, which can also cause damping-off of its favorite host (113) and the bacteria from diseased cucumber plants with which Halsted (53) caused typical damping-off of cucumbers.

Damping-off fungi with wider host ranges include *Phytophthora fagi*, *Aphanomyces levis* (100), *Rheosporangium aphanidermatus* (38, 39), *Botrytis cinerea*, and certain *Fusaria*. The so-called propagation fungus, "vermehrungspilz," a sterile damping-off mycelium which Sorauer (133, p. 321) believed related to *Sclerotinia* and for which Ruhland (115) has erected a new genus, considered by both

authors the most serious enemy encountered in growing softwood cuttings in Germany, if distinct would be a further addition to these generalized parasites. However, it is now believed (34) to be identical with *Corticium vagum*. Common generalized parasites of older plants, such as *Sclerotinia libertiana*, *Sclerotium rolfsii* (129), and *Thielavia basicola* (47), capable of attacking roots or other parts of older plants of numerous species, may also be considered among the damping-off fungi when they cause the death of small seedlings, as occurs, for example, in attacks by *Sclerotinia libertiana* on lettuce (20, p. 28) and celery (103, p. 536) in seed beds. Further study will probably result in multiplying almost indefinitely the number of more or less important damping-off parasites, both of the specialized and unspecialized groups, although the most important of the latter type are probably already known.

Most of the references in literature to damping-off describe its occurrence in truck crops and the losses caused in these crops. According to Halsted (53, p. 342), weed seedlings are also very commonly attacked. Duggar (33) names lettuce, celery, cotton, sugar beet, cress, cucumber, and sunflower as especially susceptible to injury by the two most important damping-off organisms. Except for the plant species in which damping-off by seed-carried parasites is common, it appears that the economic damage from damping-off is serious only with plants whose culture involves the raising of the seedlings in crowded seed beds for subsequent transplanting. For example, tomatoes do not ordinarily suffer from damping-off in the field (70), but the growing of seedlings in flats for subsequent transplanting is sometimes seriously hampered as a result of the prevalence of damping-off. This same principle holds in general for trees. Broad-leaved trees, which are usually not as crowded in the seedling stage as are the conifers, seldom give rise to complaint on the score of damping-off. The conifers, subject to serious losses in nursery beds, are not believed to be greatly affected in this country by the better known types of damping-off under forest conditions (68) except in the less common cases in which seedlings come up in close groups from squirrel hoards, artificial seed spots, or similar sources.

A considerable number of broad-leaved trees have been reported at one time or another as injured by damping-off, though complaints of commercially serious losses are not common. The cases which have come to the writer's attention are listed below:

Cause not determined:

Orange (43, 108).

Olive, in greenhouse at the University of California.

Russian wild olive (*Elaeagnus* sp.), serious at an Iowa nursery; oral report by Mr. C. R. Bechtel, formerly of the United States Forest Service; at another nursery in the same region this plant was reported as very little subject to injury.

Cause not determined—Continued.

Magnolia (31), troublesome if the pulp is not washed off the seed before planting.

Eucalyptus spp. (88, p. 45; 131), serious under moist conditions.

Betula spp. Communication by Dr. Perley Spaulding, of the Bureau of Plant Industry; found especially susceptible in a Pennsylvania nursery.

Carob, at United States Plant Introduction Garden, Chico, Calif. Dr.

Mel T. Cook states that damping-off is more serious in carob seedlings if the seed is removed from the pod than if pods and seeds are sown together.

Robinia pseudacacia (13).

Apple, in greenhouse at the Michigan Agricultural College.

Sclerotinia sp. (Europe):

Betula (79), a disease of seed and germinating seedlings.

Phytophthora fagi (Europe):

Fagus. Hartig (59) and many other writers; seriously affected, even in forest.

Platanus (15).

Acer (15), *A. platanoides* and *A. pseudoplatanus* (86, 104).

Robinia (59, 73).

Fraxinus (73).

Acacia (59).

Cercospora acerina (Europe):

Acer platanoides and *A. pseudoplatanus* (58).

Pythium debaryanum:

Tilia europea and *T. ulmifolia* (137), serious.

Robinia (75, p. 13-14), killing germinating seed.

Catalpa (126).

Rhizoctonia:

Citrus seed beds (130); much loss.

Catalpa (126).

Botrytis cinerea:

Catalpa (126).

Fusarium sp.:

Citrus seed beds (130); much loss.

The sugar beet is apparently the only plant whose damping-off diseases have been investigated with any degree of completeness by modern methods. While there is a great mass of literature on damping-off, it is mainly descriptive and on control measures. Most of the reports of the causal relation between the different fungi and the disease in the various host plants have been based on demonstrations of the presence of the fungus in diseased seedlings. In a great number of these cases identification has been doubtful. Even when a fungus is known to belong to a parasitic species, it is by no means certain that the mycelium found belongs to a parasitic strain. It has been found, for example, that only part of the strains of *Corticium vagum* occurring in sugar beets are able to attack that host vigorously (38, p. 154). Similar data for pine appear in figures 1 and 2. Furthermore, even parasitic strains of several of the damping-off organisms are so widely distributed as

saprophytes that one of them might easily get into a killed seedling after some other parasite had caused its death. Not only in the case of seedlings killed by fungi like *Peronospora parasitica*, but in

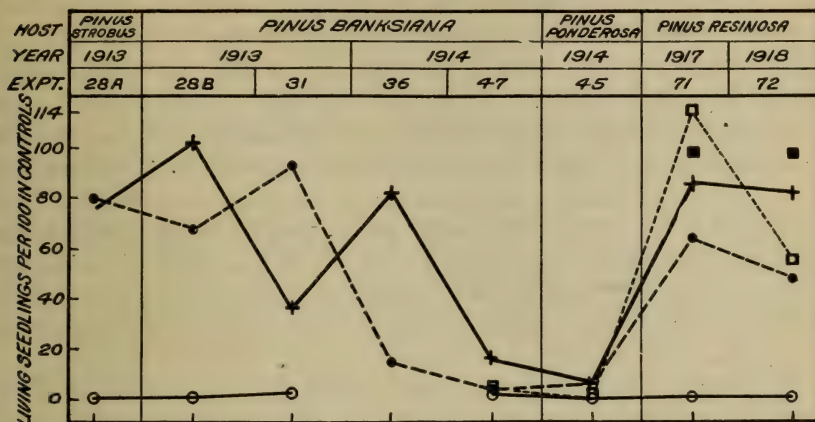


FIG. 1.—Diagram showing the relative activity of different strains of *Corticium vagum* in inoculations made at the time of sowing the seed. In experiments Nos. 36, 45, and 47 the values are plotted for the number of seedlings appearing above the soil. For the other experiments the number of seedlings surviving at the close of the experiment have been taken. Explanation of symbols: ○=Strain 147, from spruce seedlings, Washington, D. C., 1910; + =strain 50, from pine seedlings, Nebraska, 1909; □=strain 233, from *Elaeagnus* sp., Kansas, 1913; ■=strain 230, from the same lesion as strain 233; ●=strain 183, from bean, New York, 1910.

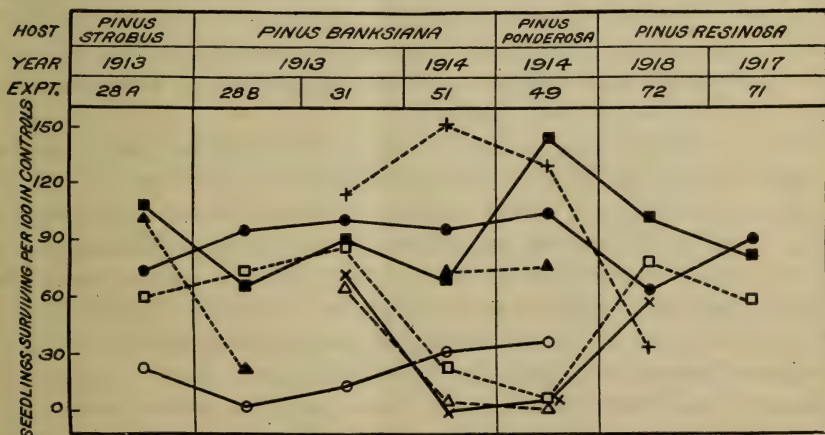


FIG. 2.—Diagram showing the relative activity of different strains of *Corticium vagum*, as indicated by the number of seedlings surviving in inoculated soil. Explanation of symbols: ●=Strain 189, from sugar beet, Michigan, 1910 (light-brown mycelium with few sclerotia); ▲=strain 211 and △=strain 212, from sugar beet, Colorado, 1910; ■=strain 186, from potato, Ohio, 1910; □=strain 187, from potato, New York, 1910; + =strain 205, from Douglas fir, Colorado, 1911; ×=strain 192 and ○=strain 206, from pine, Nebraska, 1911.

cases of true damping-off produced by the rotting type of parasite, much of the rapid decay of the seedling after death is brought about by bacteria and fungi other than the one causing death.

Inoculation experiments are therefore probably even more necessary in damping-off investigations than in studies of most other diseases in order to demonstrate etiological relationships. Unfortunately, most of the inoculation work with damping-off organisms prior to 1900 was either crudely done by placing diseased seedlings against healthy ones or consisted of experiments in which purity of cultures and validity of controls did not receive sufficient consideration. Recent investigations not primarily directed toward damping-off, but which have decidedly increased our knowledge of the relation between *Corticium* and the disease, are those of Peltier (98) and Fred (43). The latter established a strong presumption that the difficulty in securing stands of various field crops having oily seeds in soil where green manures had been recently turned under is due to the killing of the sprouting seed by damping-off organisms.

In tobacco, sugar beet, and pine, whose damping-off has received considerable attention, it has been found that the damping-off proper is commonly preceded by the killing of many of the sprouting seeds in the soil (38; 68, p. 522; 81, p. 5) and followed, after the plants become too large to be killed by the damping-off organisms, by root sickness and the death of small roots (38, p. 161; 64; 100). This latter has been reported also as a serious matter in the case of *Corticium vagum* for potato (51), a host on which damping-off is not important because of the lack of commercial propagation from seed. *Pythium debaryanum* further has been reported as continuing to work in the cortical tissues and leaves of tobacco plants which have been infected too late to result in death (81).

The fact that a number of the damping-off fungi are able to attack young or soft tissues of so great a variety of plants and are much less able to kill older plants suggests that resistance to damping-off may be in part based on purely mechanical factors. Hawkins and Harvey (71) recently have extended to *Pythium debaryanum* the idea, developed by Blackman and Welsford (12) and Brown (16) for *Botrytis cinerea*, of the importance of mechanical penetration in the fungous invasion of plant tissues. While for *B. cinerea* mechanical pressure was found to be the main factor only in cuticle penetration, with *P. debaryanum* the penetration of the cell walls of all parts of the potato tuber was apparently largely dependent on mechanical puncturing by the hyphæ, only tubers with mechanically weak cell walls being susceptible to decay by the fungus. The extreme susceptibility to *P. debaryanum* and *Corticium vagum* of soft, thin-walled tissues and the resistance of older stems and root parts would fit in well with such a theory as to the method of wall penetration, as in the older tissues the thicker cell walls would obviously be a serious bar to the extension of a fungus dependent partly or en-

tirely on mechanical puncturing for its progress from cell to cell. Hartig (61, p. 147-150) shows a fungus which he does not name, but which is evidently a species of *Fusarium*, dissolving the young uncuticularized epidermis of pine seedlings; but he states that it can not so dissolve older epidermis. The increased protective value of the epidermis of older plants can only in part explain the immunity most of them develop against serious attack by damping-off organisms, as lesions already started or which may later develop from the infection of young roots are unable to extend into the older parts of the plants.

It may be mentioned here that the writer in a very preliminary test found strains of *Corticium vagum* and *Fusarium moniliforme* Sheldon which had been proved able to cause damping-off of pines also apparently able to destroy filter paper in inorganic salt solution, while *Pythium debaryanum* seemed not so able. Ruhland (116), on the other hand, found the strain of the "vermehrungspilz" (*Corticium vagum*) which he tested to be very weak in cellulose-destroying ability as compared with *Botrytis cinerea*.

DAMPING-OFF OF CONIFERS.

HISTORICAL.

While the losses from damping-off in seed beds of dicotyledonous tree species are occasionally serious and in the case of beech in Europe have required considerable study, they have been so far overshadowed in this country by the losses in coniferous seed beds that practically all the attention thus far, both as to etiology and measures of prevention, has been devoted to the disease in conifers.

The literature on the damping-off of conifers is considerable. A large part of it, because of the extensive early development of plant pathology and forest planting in Germany, has been written by Germans. A large portion of the German articles on it was either by foresters or by botanists in the day when most pathological work was of the reconnaissance type. Therefore, while the work of one of the best known of the parasites on coniferous seedlings was noticed in Europe as early as the eighteenth century (21, p. 252-253) most of the European data available are observational. The only fungi which were at all definitely connected with the disease on conifers seem to have been *Fusarium* (*Fusoma* spp.) and *Phytophthora fagi* (*P. omnivora* De Bary in part). The damping-off Rhizoctonia was described in Germany in 1858 and *Pythium debaryanum* in 1874; the fact that neither of these, important in coniferous seed beds in both the eastern and western United States, has ever been reported from conifers in Europe is perhaps the best evi-

dence of the relatively small amount of actual investigation carried on there on this disease in the nurseries. A number of references to the damping-off of conifers in the English horticultural and botanical literature yield even less definite information as to the causal fungi than do the German articles.

With the awakening of interest in reforestation in the United States between 15 and 20 years ago and the first efforts to grow pines in quantity for forestry purposes, attempts were made to determine the cause of the disease in this country and to develop direct-control methods. Duggar and Stewart (32) made what appears to be the first report of *Rhizoctonia* in connection with the damping-off of conifers. Spaulding (136, 137), in work begun in 1905, contributed much to our knowledge of the etiology of the damping-off of pine in this country, especially in relation to *Fusarium*, and originated the sulphuric-acid method of control. The writer in 1910 reported preliminary inoculations on conifers with both *Rhizoctonia* and *Pythium debaryanum* (62). The work of Gifford (46) and Hofmann (77) added to the information on the causal relation of *Fusarium* spp. and *P. debaryanum*, respectively. Hartley, Merrill, and Rhoads (68) have recently established the parasitism of a number of strains of the *Corticium vagum* type of *Rhizoctonia* on pine seedlings under inoculation conditions, have confirmed Spaulding's conclusions as to the parasitism of *Fusarium moniliforme* Sheldon, and have given preliminary data on other fungi. They consider *P. debaryanum* and *C. vagum* more important in pine seed beds than any single *Fusarium* species. Hartley and Hahn (69) have announced successful inoculations on pines with *P. debaryanum* and *Rheosporangium aphanidermatus* Edson, with less satisfactory evidence of the parasitism of *Phytophthora* sp. and a fungus tentatively referred to *Pythium artotrogus*. Hartley and Pierce (67) report the finding of *P. debaryanum* in *Tsuga mertensiana* and *Pseudotsuga taxifolia* as well as in the pines. In damped-off pine seedlings they find *P. debaryanum* more commonly than *C. vagum*, especially in beds which have received disinfectant treatments. Other considerations, however, keep them from concluding that the former is necessarily the more important of the two. Both of these latter papers and all of the reports of *Pythium* with the exception of Hofmann's are brief notes, presenting no evidence in support of the statements made.

DESCRIPTION.

The symptoms of damping-off in conifers have already been described in some detail (68). In the paper cited, injury due to excessive heat of the surface soil and injury caused by high wind, both of which may easily be confused with damping-off, are described and accompanied by colored illustrations both of different types of damp-

ing-off and of these nonparasitic troubles. The detailed descriptions will not be repeated here. A brief summary of the different types of disease recognized as included in damping-off follows:

(1) Germination loss: The radicles are killed very soon after the seeds sprout and before the seedlings can appear above ground. This is an important type, which can be caused probably by any of the organisms commonly capable of causing the better known types of trouble (61, 63, 68, 137).

(2) Normal damping-off (figs. 3, 4, and 5): The seedlings are killed by fungi invading either the root or hypocotyl after the seedling has appeared above the soil and while the stem is still dependent largely on the turgor of its cortical tissues for support. In sandy soils root infection is more common than hypocotyl infection, though the latter is the type most emphasized in the early horticultural descriptions. Büttner (26) some time ago recognized the frequency of



FIG. 3.—Normal type of damping-off of *Pinus ponderosa*. At the left is a damped-off seedling or root sprout of the southwestern ragweed (*Ambrosia psilostachya*). (Photographed by S. C. Bruner.)

root infections. Damping-off in beds out of doors is primarily in most cases a root rot, either of this type or of the types preceding and following.

(3) Late damping-off includes cases of the root-rot type occurring only after the seedling stems have started to become woody and the cortex has begun to shrivel. The damping-off parasites, or at least part of them, continue to kill seedlings by rotting their roots for some time after the stems become too woody to be decayed. The seedlings affected do not fall over till a considerable time after death. For convenience, all cases of this sort up to the purely arbitrary age of two months are classed as damping-off. However, in weather permitting of average speed of development the seedlings are usually able to resist attack before they reach this age. Seedlings at the marginal age between susceptibility and nonsusceptibility to killing infections are found often with the younger parts of their roots killed, but with the older portions apparently able to resist invasion by the fungus, recovery taking place by laterals. Dr. R. D. Rands and the writer in 1911 established the ability of seedlings from 43-day-old beds of *Pinus sylvestris*, *P. banksiana*, *P. nigra austriaca*, and *P. nigra poiretiana* to survive such infections, even when more than half of the root system has been destroyed, by transplanting such root-sick seedlings and

observing their continued growth (fig. 6). An article recently found (25) shows that Büttner had earlier made the same sort of demonstration of recovery of root-sick conifers. Observations on olive seedlings in 1916 showed cases of partially rotted roots which were recovering by sending out lateral root branches.

(4) Top damping: The cotyledons or upper part of the stem are invaded by the parasite, sometimes before the seedling breaks through the soil. The infection may or may not be fatal. A special case of this type, probably caused by a different parasite from those most commonly active, is that which in a publication above referred to was described and figured as "black-top" (68). It is

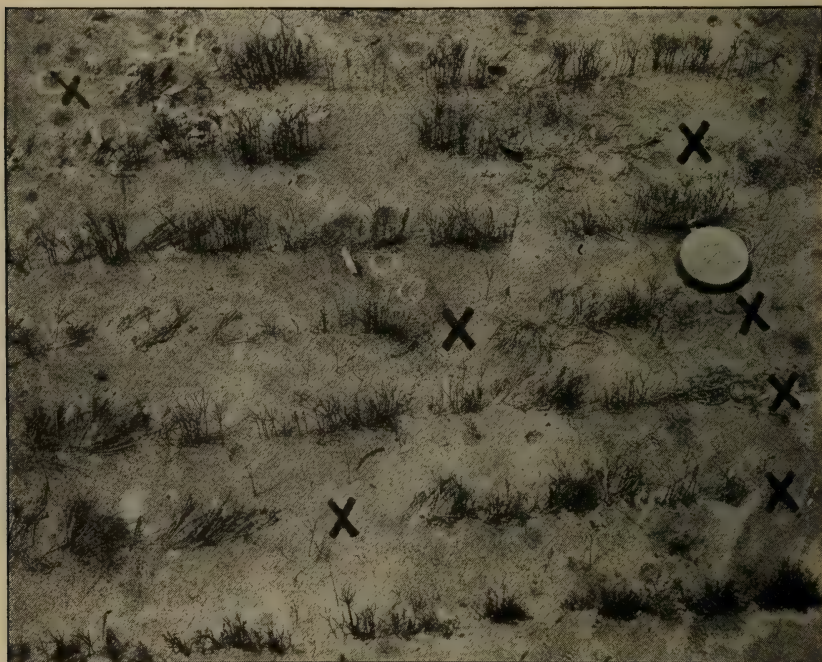


FIG. 4.—The beginning of an epidemic in drill-sown *Pinus banksiana*. Black crosses (X) indicate disease foci where the germinating seed were apparently killed and from which the disease is now spreading to adjacent seedlings. (Photographed by Dr. J. V. Hofmann.)

distinguished from ordinary top damping by the very dark color of the invaded tissues and its apparent dependence on some unusual set of climatic factors for its progress in the seedling after infection.

The killing of dormant seed by fungi is a matter of some practical interest in seed beds, and possibly still more so in forests, as it may help to explain the failure of certain conifers to reproduce except on mineral or certain other special soil types (68). With sugar beets *Pythium debaryanum* (100) is said to attack dormant seed as well as seeds which have sprouted. It is to be presumed that with conifers some of the damping-off fungi will be found to attack dormant as well as sprouting seed. This matter is now under investigation.

Something is already known about the seed fungi of herbaceous plants (76, 91), broad-leaved trees (79, 92), and juniper (95).

RELATIVE IMPORTANCE OF THE DIFFERENT TYPES.

Of the types of damping-off described in the foregoing pages the first two are ordinarily the most important. Late damping-off is rarely as serious as the normal type of damping-off. Top damping is only of importance in cases of excessive and unusual atmospheric moisture, so far as the writer's experience indicates. In the Middle West it has proved relatively insignificant. The three types which



FIG. 5.—Nearly complete destruction of the seedlings of *Pinus banksiana* at an unusually early age, at Garden City, Kans. (Photographed by Dr. J. V. Hofmann.)

occur after the seedlings appear above the soil surface can, of course, be evaluated by frequent counts during the damping-off season. This has apparently not yet been done by anyone. However, in experiments on damping-off control by soil disinfection, data have been obtained on comparative emergence (number of seedlings appearing above the soil surface) in treated and untreated plats and on the total parasitic losses after the seedlings appear which permit a certain amount of analysis of the losses due to damping-off parasites. The data from five nurseries bearing on this point are presented in Table I.

TABLE I.—*Relative importance of losses by damping-off before and after conifer seedlings emerge from the soil.*

Nursery and species.	Series.	Basis.		Loss in control plats.				
		Disinfectant.	Number of plats.		Emerg'd (viable seeds).			Ratio of col. 6 to col. 7.
			Treat- ed.	Con- trols.	Be- fore.	After.	Total.	
1	2	3	4	5	6	7	8	9
Bessey (Nebraska sand hills):					<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	
Pinus banksiana.....	Average of 9....	Sulphuric acid	(a)	(b)	37.8	27.2	65.0	c 1.39
Pinus ponderosa.....	Average of 2....	do.....	6	8	28.1	27.3	55.4	1.03
Pinus resinosa.....	Average of 3....	do.....	4	7	29.4	54.1	83.5	.54
Garden City (southwestern Kansas):								
Pinus austriaca.....	Average of 2....	Copper sul- phate.	4	3	69.0	27.5	96.5	2.52
Pinus banksiana.....	do.....	Zinc chlorid..	3	2	80.7	12.0	92.7	6.72
Pinus ponderosa.....	Average of 7....	Copper sul- phate.	17	29	15.3	30.9	46.2	.49
Cass Lake (northern Minne- sota):								
	{No. 1051.....	Formaldehyde	6	3	3.8	37.2	41.0	.10
	{No. 1052.....	do.....	6	3	25.7	36.2	61.9	.71
	{No. 1053.....	Zinc chlorid..	4	4	5.7	26.2	31.9	.22
Pinus resinosa.....	{No. 1054.....	do.....	4	3	7.4	43.6	5.1	.18
	{Nos. 1057 and 1061.	Heat.....	4	2	4.9	16.9	21.8	.29
East Tawas (Michigan):								
Pinus resinosa.....	{1073.....	Formaldehyde	6	3	5.9	45.3	51.2	.13
	{1074.....	Sulphuric acid	2	7	58.2	18.0	76.2	3.25
Fort Bayard (New Mexico):								
Pinus ponderosa.....	{Nos. 791 and 792.	Formaldehyde	7	8	12.6	36.1	48.7	.35
	{Nos. 891 and 892.	Sulphuric acid	8	6	14.5	18.6	33.1	.78

^a Area counted, 122 square feet.^b Area counted, 78 square feet.^c In *Pinus banksiana* at the Bessey Nursery, the loss after emergence is slightly low and the ratio slightly high, because of the closing of counts on a few of the series before damping-off was entirely over.

The procedure was to average the number of seedlings which emerged in the control plats in each series and subtract this number from the average number emerging (that is, appearing above the soil surface) in the treated plats in the same series. The treated plats chosen were the ones which allowed the averaging of the greatest number of plats treated with the same disinfectant. Only those plats were taken in which there was no evidence of injury to the seed or seedlings by the disinfectant and in which the amount of normal damping-off during the first few days after emergence was so slight as to indicate satisfactory initial control of the parasites by the treatment. In such plats it was assumed that the germination loss was unimportant, and the average number of seedlings appearing on them was taken as representing the number of viable seeds per plat. The difference between this emergence figure and the average emergence in the controls was taken as indicating the extent of parasitic loss before the seedlings appeared, including any destruction of dormant seed by parasites which may have occurred as well as the killing of germinating seed. Both this figure and the number

of seedlings which succumbed to damping-off after emergence were reduced to a percentage based on the indicated number of viable seeds, and they are directly compared in columns 6 and 7 of Table I. At three of the nurseries the data of the same species of pine and with the same treatment were averaged.

The data in Table I do not indicate any regularity either in the extent of loss before emergence, the loss after emergence, or in the ratio between these two values. For obvious reasons, no regularity is to be expected in any of these items. The table is of some interest, however, in confirming the evidence of the inoculation experiments, of observation of sprouting seed dug up in the beds, and of the partial or complete failure of emergence at the centers of large damping-off foci (figs. 4, 7, and 8) that the work of parasites before the seedlings appear may in some cases be of considerable importance. It is obviously impossible to make any general quantitative statement of the seriousness of such loss, in view of the variation in its extent at different times and places and of the in-

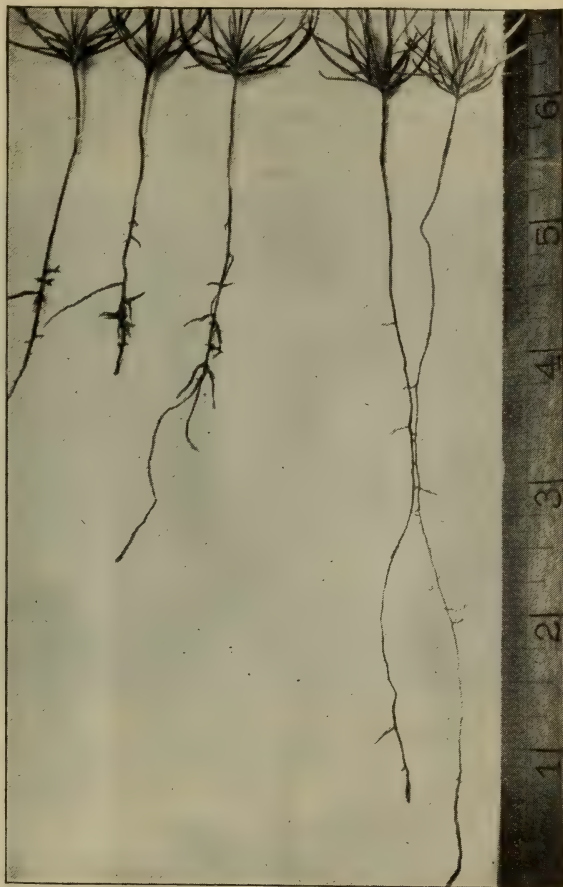


FIG. 6.—Root sickness in *Pinus nigra poiretiana*. The two seedlings at the right are healthy. The three at the left have had their taproots decayed to within $1\frac{1}{2}$ inches of the soil surface. All are putting out lateral roots from the lowermost sound point. Similarly injured seedlings when transplanted lived and made satisfactory growth.

accuracy of any computations based on the relative emergence of hosts as irregular in their germination as the conifers are known to be. The case is complicated in addition by the fact that, despite careful avoidance of treated plats known to have suffered chemical injury, it is probable that a few seedlings were killed before emergence by the disinfectants used in some of the

cases. It may furthermore be that in other cases the disinfectant had a stimulating effect, resulting in better germination in the treated plats, entirely aside from that resulting from parasite control. The number of disinfectant methods which concurred in giving apparent increases in germination, however, makes it seem reasonably certain that no great part of the increase was due to this stimulation.

In addition to the different disinfectants shown in the table, mercuric chlorid, heat, hydrochloric acid, nitric acid, and ammonia all apparently resulted in approximately the same increases of germination in tests at the Bessey Nursery as the sulphuric acid which was used as the standard for comparison in most of the series. Relative emergence in treated and untreated plats, as well as damping-off



FIG. 7.—A clean-killed area in a bed of *Pinus ponderosa*, caused by *Corticium vagum*. Inside a 12-inch circle at the center of this "patch" no seedlings appeared. It will be noted that the weeds as well as the pines have been killed with the exception of *Salsoia tragus*.

loss after the seedlings appeared, was determined at two nurseries in addition to those given in the table. The results at these nurseries in general confirmed those at the five nurseries covered by the table in showing lower emergence in the controls. Although it is impossible to draw positive conclusions, some idea of the seriousness of losses before the appearance of the seedlings above ground can be obtained by studying the data in Table I. The fact that such losses appear considerable, sometimes exceeding the losses from the damping-off that occurs after emergence, is believed to explain the common failure to secure satisfactory results from control measures taken after the seedlings have come up and the disease has become noticeable. It is somewhat interesting to note that the data in the

table tend to confirm field observations that, as compared with other species, *Pinus resinosa* is more susceptible to the later forms of damping-off than to germination loss.

Further indication that the killing of germinating seed before emergence may be important enough to help explain cases of poor germination is obtained by an entirely different method, as follows: At the Wind River Experiment Station of the United States Forest Service counts of the seedlings emerging and of those which later died were made on a number of untreated plats by forest officers, who kindly permitted the writer to use the data obtained. The counts were made separately on 10 plats each of noble fir (*Abies nobilis*) and silver fir (*Abies concolor*). The plats of each species had been sown with equal quantities of seed. It appeared on inspection of the figures that the plats which showed the poorest emer-

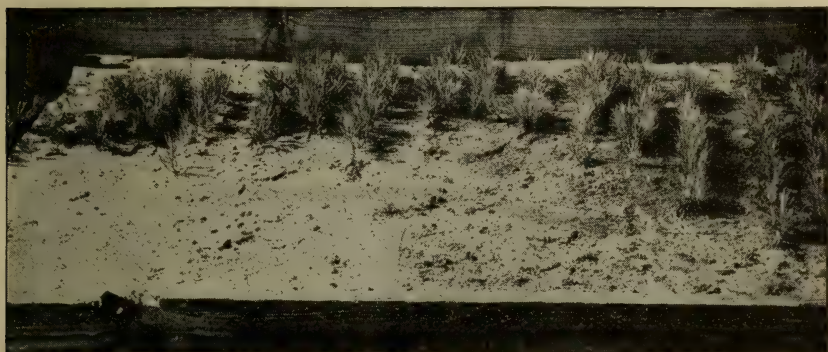


FIG. 8.—The area shown in figure 7 after the bed had been weeded and damping-off had practically ceased. (Photographed by S. C. Bruner.)

gence were also the ones which suffered the most subsequent loss. The coefficient of correlation between the number of seedlings emerging and the percentage of subsequent loss in the same plats was found to be -0.49 ± 0.16 for the noble fir, and -0.50 ± 0.16 for the silver fir, an average of -0.49 ± 0.11 for the two species, confirming the conclusion drawn from inspection of the figures. In other words, poor emergence and heavy subsequent loss were in general associated. The simplest explanation of this association appears to be to suppose that both poor emergence and subsequent loss were largely due to the same cause, namely, the damping-off parasites. Another possible explanation of the correlation would be to neglect parasites as important causes of the poor emergence in certain plats and to suppose that the higher subsequent loss in such plats was due to heat injury, the less dense stands affording less shade to the bases of the seedlings composing it. As damping-off is in general so much more important than heat injury as a cause of death after emergence and the difference in the degrees of shade between the plats with the denser

and the plats with the thinner stands must have been very slight, this latter explanation has not much to support it. The data are believed to constitute further evidence of the importance of parasites in decreasing the percentage of emergence in coniferous seed beds. That the effect of parasites on emergence should have been large enough in this case to make itself apparent on the face of the figures, despite the variations due to other sources, is especially interesting in view of the fact that the losses after emergence in these plats were not high.

ECONOMIC IMPORTANCE OF DAMPING-OFF.

The importance of damping-off in coniferous nurseries in Europe is indicated by frequent reference to the disease in the literature. Büttner (25, 26) states that whole beds are frequently destroyed by it. Baudisch (9) speaks of the death of entire stands in many nurseries as the result of damping-off. In the United States Spaulding (137) considers damping-off a serious obstacle in forestation operations. Clinton (28, p. 348-349) reports serious damage to conifers in New England nurseries. The writer has found the disease especially prevalent in nurseries in Nebraska and Kansas, a somewhat unexpected situation in view of the relatively dry conditions prevailing there. A correspondent has reported heavy loss in seed beds in Texas.

The economic importance of the disease in conifers is due in part to the rather heavy average losses experienced at many nurseries and in part to the irregular character of the losses. In one season losses may be negligible, while the next season the beds of certain species may be practically wiped out. Even without this element of uncertainty the losses experienced are expensive, because of the high cost of coniferous seed. The seed of some species costs from \$3 to \$5 a pound and seldom shows a germination of more than 60 per cent under nursery conditions. A loss of half of this 60 per cent from parasites, both before and after the seedlings break through the soil, is therefore a matter which deserves attention. The figures in column 8 of Table I, obtained by adding together those in columns 6 and 7, show that the loss is frequently higher than this. At the nurseries at which control experiments have been conducted, the percentage of the seedlings in untreated beds which have been found by actual count damped-off after emergence is frequently more than 50 per cent, in addition to the considerable but less accurately determinable loss indicated by the foregoing data as being caused by the parasites before the seedlings appear.

It has been suggested by foresters and others that the net economic damage from damping-off is not as great as is indicated by the loss of seed and seedlings which it may cause. The argument is ad-

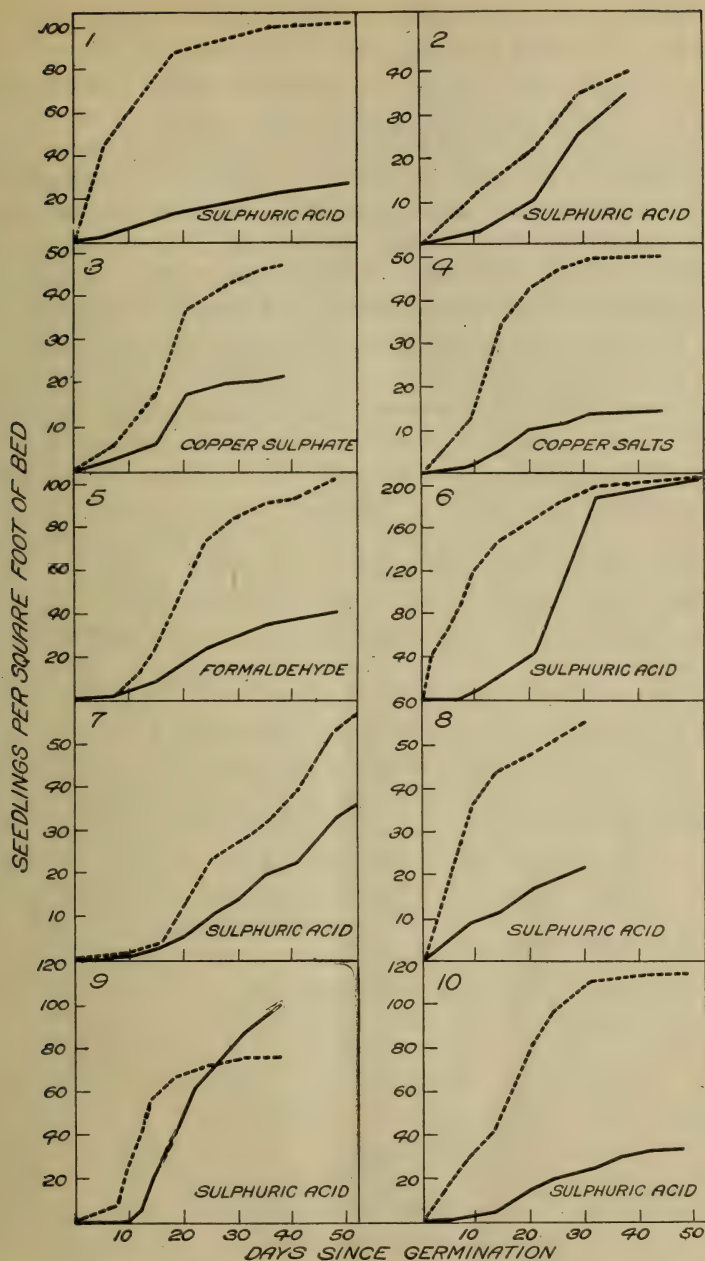


FIG. 9.—Diagram showing the progress of damping-off in treated plots (solid line) as compared with untreated plots (broken line). Graphs 1 to 4 represent *Pinus ponderosa*; graphs 5 to 8, *P. resinosa*; graph 9, *P. banksiana*; and graph 10, plots each of which was half *P. nigra poiretiana* and half *P. sylvestris*. Nurseries in Kansas, Nebraska, Minnesota, and Michigan are represented. The relatively high total number damped-off in the treated plots shown in two of the graphs is due to the fact that a large proportion of the seedlings in the untreated plots had been killed before they appeared above the soil surface. In both the cases in which the absolute number of seedlings in the untreated plots killed was as great as in the controls, the percentage of the seedlings killed was nevertheless lower and the survival more than twice as good as in the controls.

vanced that damping-off may be a valuable selective agent in nursery-grown stock for forest planting, eliminating the weaker individuals and thus insuring the vigor of the trees which go into the forest plantation. This is a possibility which must be considered. It is by no means certain, however, that escape from damping-off is correlated with permanently superior vigor. It is believed that temperature, moisture, and other environmental factors, which as yet are very imperfectly analyzed, together with the age of the seedlings and the presence or absence of virulent strains of the parasites, are much more important factors than inherent differences in individual resistance in determining whether or not seedlings are destroyed. Evidence from inoculation experiments and from field observation, supported by data of the sort presented in Table I, indicate that damping-off ordinarily does a considerable part of its damage by killing the sprouting seed before emergence from the soil, while the graphs in figure 9 show that of the loss which occurs after emergence in untreated beds a large part occurs very early in the life of the seedlings. Observation of the clean sweeps which the disease commonly makes in the immediate neighborhood of infection foci (figs. 3, 4, and 5) indicates that either before or just after the seedlings break through the soil none of them have any considerable resistance to the really virulent strains of the parasites, which are believed to be the ones responsible for the major share of the damping-off.

Even if there should be found to be an appreciable selective value in damping-off, this would not be a valid argument against control by seed-bed disinfection for the following reason: The graphs showing the course of damping-off in treated plats in figure 9, together with the decided differences in germination between treated and untreated plats, indicate that the very early damping-off is more completely controlled by disinfectants than the later damping-off. This early damping-off which the treatments so largely prevent is the part of the loss which has the least possibility of selective value. The later damping-off is rarely controlled at all thoroughly by disinfectants. As shown by the graphs, it is often even heavier on the treated than on the untreated soil. It is the part of the loss which is most likely to have selective effect. At this stage beds are not taken clean, as earlier; only seedlings which are below normal resistance succumb. The damping-off in disinfected beds seems therefore at least as likely to have true selective value as that which occurs in untreated beds.

The only way in which the effect of damping-off as a selective agent can be positively determined will be to compare through several subsequent years the growth rate, or survival after transplanting, of trees from beds which suffer seriously from damping-off with the growth of trees from the same lot of seed in seed beds in

which the disease is either accidentally absent or is artificially controlled. Such an experiment is within the silvical rather than the pathological investigative field. If it be found that there is some selective value in the action of the disease and that it is greater in untreated than in treated beds, it would still seem that a much more desirable and dependable selection could be obtained by discarding weak plants at the time of transplanting than by letting damping-off run uncontrolled in the seed beds. Damping-off is sometimes negligible and sometimes destroys practically all the seedlings in a given area, in neither of which cases can it have any material selective value.

RELATIVE SUSCEPTIBILITY OF DIFFERENT CONIFERS.

Büttner (25) writing of European conditions, states that exotic conifers are especially subject to damping-off. He includes fir, spruce, pines, larches, and cypress in this statement. He mentions the same subject in a later paper (26). Neger and Büttner (94) give a long list of different species of conifers from various parts of the world with statements as to their susceptibility to damping-off. Beissner (11, p. 656-657), Neger (93), Clinton (28), Bates and Pierce (7), Boerker (13), and Tillotson (139, p. 69) have all given information on the susceptibility of different conifers. The data reported by Tillotson are drawn from reports by various officers of the United States Forest Service which he has compiled. While it is probable that the nurserymen who are responsible for most of his records have not observed the disease as closely as Neger and Büttner, the fact that their observations are mostly based on repeated seasons' work with large-scale seed beds of the species they report on makes their observations in some respects more reliable than the other published data. Neger and Büttner presumably worked in most cases with small beds of the various conifers on which they report, and the variations which they attribute to differences in specific resistance might easily in such case be largely due to accidental variation. The error which nurserymen are most likely to make in their notes on susceptibility is to underestimate the loss, especially for the small-seeded species. The seedlings of small-seeded conifers decay and shrivel so quickly after they fall that in taking notes at any one time only a small proportion of the total loss is visible. Frequent counts of dead seedlings are the only way by which the loss after germination in such species can be properly appreciated.

The data given by the authors mentioned in the foregoing paragraph, together with unpublished data obtained by personal observation or from commercial and other nurserymen in the United States, are summarized in Table II, the source of each report being shown by letters signifying the authority. The unpublished data on two

nurseries in Illinois and Minnesota were obtained from the nurserymen by Mr. R. G. Pierce and are indicated by the initial "P." Information obtained directly from the nurserymen by the writer is indicated by "N." For nurseries where the statements are based on the writer's personal observation rather than on the authority of the nurserymen, his own initial ("H") is given. Most of the writer's own estimates of relative susceptibility are based on a comparison of detailed counts of the damped-off seedlings in a large number of untreated plats at different times, as well as on observation. The nurseries on which Tillotson reported were all west of the Missouri River, most of them being in the mountain region. The reports indicated by "H" and "N" were mostly from nurseries east of the Rocky Mountains. In cases in which the data permit it, the species are classified as most susceptible, intermediate, least susceptible, or immune. In a number of cases, however, it is only possible to classify them as "more" or "less" susceptible.

TABLE II.—*Relative susceptibility to damping-off of different conifer species.*
[Figures in parentheses in this table indicate the number of nurseries from which the susceptibility noted has been reported by the observer to whom the preceding letter refers.]

Host species. ^a	Reports of relative susceptibility. ^b					
	Not susceptible.	Least susceptible.	Less than average.	Intermediate.	More susceptible than the average.	Most susceptible.
Pinaceæ (Abietoideæ):						
Abies spp.		(c)				
Abies balsamea.....		Nb.				
Abies cephalonica.....				Nb.		
Abies concolor.....						Bu, Nb.
Abies nobilis.....			T.			Nb.
Abies nordmanniana.....				Nb.		
Abies picea (A. pectinata).....				Nb.		
Abies sacchalinenensis (?).....				Nb.		
Abies sibirica.....		Nb.				
Abies veitchii.....						Nb.
Cedrus deodara.....			T.			
Larix europæa.....				Nb.	N (2)	
Larix leptolepis.....						Nb.
Larix occidentalis.....			T.		T.	
Picea ajanensis.....			Ne.	Nb.		
Picea canadensis.....		Nb.		P.	N.	
Picea engelmanni.....			T (2)		H, N, Ne, T.	Nb.
Picea excelsa.....	P.	Nb.	H, Bu.		Ne, N.	
Picea omorika.....			Ne.	Nb.		
Picea orientalis.....			Ne.	Nb.		
Picea pungens.....			N (2)	H, P.	Ne.	N (2), Nb.
Picea sitchensis.....					Ne.	Nb.
Pinus aristata.....		Nb.			N.	
Pinus attenuata.....						
Pinus banksiana.....		Nb.	N.	P.	B, P, H (2), T.	B., H.
Pinus contorta.....	T.	Nb.	T.			
Pinus edulis.....	T.					

^a Host names for American species follow the usage in the publications and a later verbal communication of Mr. George B. Sudworth, of the United States Forest Service. For exotic species the Standard Cyclopedia of Horticulture, New York, 1916, edited by L. H. Bailey, is taken as the standard. The classification follows Saxton (118).

^b Symbols signifying the authority for the report: B=Boerker (13), Bu=Büttner (25, 26), Bp=Bates and Pierce (7), C=Clinton (28), H=Writer's estimate, N=Nurserymen's estimate (obtained by the writer), Nb=Neger and Büttner (94), Ne=Neger (93), P=Nurserymen's estimate (obtained by Pierce), T=Forest officers' estimate (compiled by Tillotson, 139).

^c Susceptibility to *Phytophthora jagi*.

TABLE II.—*Relative susceptibility to damping-off of different conifer species—Continued.*

Host species.	Reports of relative susceptibility.					
	Not susceptible.	Least susceptible.	Less than average.	Intermediate.	More susceptible than the average.	Most susceptible.
Pinaceæ (Abietoideæ)—Continued.						
<i>Pinus excelsa</i>		Nb.				
<i>Pinus flexilis</i>		N.				
<i>Pinus jeffreyi</i>			T		T (2).	
<i>Pinus lambertiana</i>				P	T	
<i>Pinus montana</i> mughus.						
<i>Pinus monticola</i>	T		T		T	
<i>Pinus nigra austriaca</i> (Austrian pine)		Nb.	N, T (3)		Bp, N, T	
<i>Pinus nigra poiretiana</i> (Corsican pine)	Bp.		H			
<i>Pinus palustris</i>			B			
<i>Pinus peuce</i>		Nb.				
<i>Pinus ponderosa</i> (type not specified).....	T (3).	P	Bp, N (4), T (6).	Nb.	T (4).	
<i>Pinus ponderosa</i> (Eastern Rocky Mountain type).....			H (4).		B.	
<i>Pinus ponderosa</i> (Pacific coast type).....			B			
<i>Pinus resinosa</i>			N (3)		Bp, H, T.	B, H.
<i>Pinus rigida</i>			P		N	
<i>Pinus strobus</i>	P		B, H, N	N	C, N, T.	
<i>Pinus sylvestris</i>			T (2)	H, P	Bp, T (3)	N.
<i>Pinus taeda</i>		B.				
<i>Pinus thunbergii</i>		Nb.				
<i>Pseudotsuga taxifolia</i> (type not specified)			N (3) T (3)	H	N, T (5)	
<i>Pseudotsuga taxifolia</i> (Colorado type)		Nb.			B	
<i>Pseudotsuga taxifolia</i> (Northwestern type).....		B		Nb.		
<i>Tsuga canadensis</i>				Nb, P.	Bu	
Number of reports.....	9	17	51	23	48	15
Percentage of total.....	6	10	31	14	29	9
Sciadopitoideæ:						
<i>Sciadopitys verticillata</i>						Nb.
Cupressaceæ (Cupressoidæ):						
<i>Chamaecyparis lawsoniana</i>		Nb.	T		Bu	
<i>Chamaecyparis pisifera</i>		Nb.				
<i>Cryptomeria japonica</i>				Nb.		
<i>Cupressus</i> spp.....		Nb.				
<i>Cupressus arizonica</i>	N					
<i>Juniperus communis</i>	Nb.			P		
<i>Juniperus monosperma</i>	N					
<i>Juniperus pachyphloea</i>	T					
<i>Juniperus virginiana</i>	H, P	Nb.				
<i>Libocedrus decurrens</i>	T	Nb.	T			
<i>Taxodium distichum</i>		Nb.				
<i>Thuja occidentalis</i>	P	Nb.				
<i>Thuja orientalis</i>	P			Nb.		
<i>Thuja plicata</i>				Nb.		
Number of reports.....	9	7	2	4	1	0
Percentage of total.....	39	30	9	17	4	0
Sequoideæ:						
<i>Sequoia</i> spp.....					B.	
<i>Sequoia washingtoniana</i>					T.	
Taxaceæ:						
<i>Taxus cuspidata</i>	P					

The fact most evident in Table II is the extreme variation between reports, not only on closely related species but even on the same species. While it is, of course, possible that the obvious lack of a definite basis and method of comparison in most of the reports is responsible for most of this variation, it seems to the writer more probable that different species do actually vary in their relative susceptibility to damping-off in different localities. In the first place,

the conditions which might increase resistance of one host might very easily decrease its resistance for a host with different environmental requirements. To illustrate by an extreme example, the piñon (*Pinus edulis*) of the arid or semiarid region might remain resistant in soils in which *Picea engelmanni* of the high mountain-stream bottoms or *Picea mariana* of the northern swamps might be low in vigor and easily attacked. In the second place, it is to be expected that species with a certain order of relative susceptibility to the parasites which predominate at one nursery may exhibit a very different order of susceptibility to the different combination of parasites which might be prevalent in another locality.

The only individual species on which there are a sufficient number of reports and a sufficient agreement between the reports are the two common western spruces, *Picea pungens* and *P. engelmanni*, which (at least as compared with *Picea excelsa*) seem rather susceptible, and *Pinus ponderosa*, which (as compared with most of the other species of the Abietoideæ) is to be regarded as generally more resistant than the average. Within each of the larger genera of this group it seems evident that susceptibility is extremely varied and that no statement as to the relative susceptibility of the genera themselves can therefore be made. The only group generalization that is perhaps permissible is derived from the consideration of the Cupressoideæ. In this group, out of 23 reports, 16 are in the "not susceptible" or "least susceptible" columns and only one indicates more than intermediate susceptibility. Of 163 reports pertaining to the Abietoideæ, only 26 place them in the "not susceptible" or "least susceptible" columns and 63 in the classes of more than intermediate susceptibility. The general feeling among nurserymen seems to be that serious damping-off need not be feared among the cedars and their relatives. The data at hand tend to justify this confidence.

CONTROL OF DAMPING-OFF.

Early efforts to prevent damping-off were chiefly directed to the avoidance of excessive moisture in either the air or soil. A means to this end, which has been observed more or less by nurserymen for many years, both in the United States and elsewhere, is the application of small quantities of dry sand to the seed beds after the disease becomes noticeable (18, p. 166; 83). This is sometimes applied hot (101, p. 43-44; 145), though even this procedure does not result in very great advantage. Surfacing with hot sand can not always be counted on to give any measurable advantage over untreated beds (67, p. 3). The use of sand (25) or sterile subsoil (101) instead of ordinary soil in covering seed at the time of sowing has been advised. Johnson (82) did not secure satisfactory results with sand in tobacco

beds. Making the upper part of the bed to a depth of several inches of recently dug subsoil appeared effective in a single test by Spaulding (137) and at four nurseries by cooperators of the writer in later tests, the results of which will be published elsewhere. The procedure is unfortunately rather expensive in large-scale work and under some conditions at least undesirable because of the poor subsequent growth on such soil. Excessive vegetable matter (45), imperfectly rotted manure (67), or green manures recently plowed under (43) have all been advised against as likely to favor the disease. The experience reported with conifers (67, 139) indicates that damping-off can be to a certain extent decreased by broadcast sowing as compared with sowing in drills. The usual recommendation of thin sowing to avoid the seed-bed disease of other plants has also been made for conifers (67). Transplanting healthy seedlings from infected beds into new soil is recommended as a means of saving them from attack (11, 145). The writer's tests of transplanting at a Nebraska nursery gave no promise of economic value as a control method, although he is informed that it was successfully employed in a nursery in New Mexico. The time of sowing appears to have a relation to the amount of disease at some nurseries, but conditions in this regard evidently differ in different localities, so that the best time to sow from the standpoint of avoiding damping-off must be determined separately by repeated tests at each nursery. For example, observations both by the nurserymen and the writer during several seasons at the Bessey Nursery, in Nebraska, indicate that fall sowing is an excellent means of decreasing loss from damping-off in at least one pine species, and Retan (110) reports the same thing for a nursery in Pennsylvania, while at two Kansas nurseries and at nurseries mentioned by Tillotson (139) fall-sown beds suffer more than those sown in the spring.

Treatment of the seed with mercuric chlorid (25) or with copper sulphate (122) has been recommended. While it has been demonstrated (38) that a proper heat treatment of the seed will greatly decrease the damping-off in sugar-beet seedlings, this is explained by the fact that one of the most important parasites of the sugar beet is systemic and often present in the seed. There is no reason to believe that seed-carried infection is of any importance in coniferous seed beds. The only advantage that could reasonably be expected from a seed treatment of conifers would be that which would come from the prevention of seed decay in the soil before germination starts, and this protection could be expected to be effective only if a relatively insoluble disinfectant, such as Bordeaux mixture, was used.

Soil treatment is the most direct and probably the most profitable method of attack on the disease. It is especially easy, for tobacco

seedlings (82) as well as for pines, to prevent by soil disinfection losses before the seedlings appear above the ground. Heat disinfection of seed beds has been frequently mentioned. Burning wood or litter on the surface of the beds before sowing, said by Gilbert (47, p. 36) to be a common procedure in preparing tobacco seed beds both in Italy and in parts of this country, has been recommended for coniferous seed beds by Büttner (25). The disadvantageous results sometimes noticed following the application of wood ashes to pine seed beds may prove an objection to this type of treatment in some of the nurseries. At a Nebraska nursery (67) moist heat proved only partly satisfactory, unavoidable reinfection having serious results. Steam disinfection, using the inverted-pan method commonly advocated for tobacco seedlings (10, 47, 81), has been reported by Scott (123) as successful at a nursery in Kansas. Gifford (46) found steaming with the inverted pan only partly satisfactory. It is not believed that it is likely to pay to install the necessary apparatus for steam disinfection at nurseries in nonagricultural districts where steam tractors are not available for temporary use. The hot-water soil treatment as used by Byars and Gilbert (27) is probably worth a trial at any nursery where damping-off is serious and fuel cheap. It may be that in some localities where steam or hot-water treatment of the soil is not sufficiently effective, its efficiency can be increased by reinoculating the soil immediately after treatment with saprophytic molds and bacteria to provide maximum competition for parasites which come in from the outside. Tests of this procedure will be described later in the present bulletin. The value of charcoal has been emphasized by Retan (109, 110).

Chemical disinfection of the soil has also been employed. Sulphur has long been in use as a soil treatment against the damping-off of various plants (45, 111) in addition to its use in combating potato scab and onion smut. It was tested on conifers by Spaulding (136, 137) in the form of light surface applications to the beds after germination, but without decisive result. In later cooperative tests powdered sulphur raked into the soil before the sowing of the seed failed to indicate any large measure of value. Very finely divided forms of sulphur in various amounts and times of application are probably worth some further test.

Möller (90) and Sherbakoff (128) have reported the successful use of copper sulphate in combating attacks of *Corticium* on dicotyledons. In Johnson's experiments on tobacco seedlings (82, table 3) copper salts and Bordeaux mixture were the only chemicals for which any value was indicated. Sherbakoff apparently used copper sulphate and other strong disinfectants chiefly to stop the extension of vigorously spreading damping-off foci by local treatment rather than as a general treatment for use over the beds. Such treatment

would presumably kill all seedlings on the area treated, but would, of course, be of considerable value in stopping at the outset such mycelia as those which caused the damped-off area in figure 7. The procedure would be of practical value only in cases in which damping-off was chiefly limited to a few large patches of this sort, a rather rare condition in conifers.

Copper sulphate solutions have been used on pine seed beds at the time of sowing with considerable success at some nurseries (65, 67). Except in a nursery in which the soil contained carbonates, it has proved rather difficult to prevent injury to the pines. The trial of some such combination of copper sulphate and lime as was used by Spaulding (136) on the surface of pine beds before sowing, which apparently prevented the damping-off of lettuce in some unpublished pot experiments of Mr. J. F. Breazeale, is considered desirable. Treating seed beds with ordinary Bordeaux mixture has also been recommended. Horne (78) secured especially good results against *Corticium vagum* in tobacco seed beds by heavy applications of Bordeaux mixture, and Schramm (122) and Clinton (28) have obtained indications of its value as a spray in preventing the damping-off of conifers. It is probably worth further tests in various amounts of application. In tests conducted by the writer in 1912 and still unpublished, some advantage was indicated for Bordeaux mixture as a surface treatment after soil disinfection with acid. Zinc chlorid as a soil disinfectant has also been found valuable in a number of cases (65, 67), but it is more expensive and apparently less dependable than copper sulphate.

Formaldehyde and sulphuric acid have been tested more frequently than other disinfectants. The use of sulphuric acid on coniferous seed beds was originated by Spaulding (136). The first intensive experiments with this acid were reported by the writer (63). The first experiments with formaldehyde on conifers seem to have been in the early greenhouse tests of Spaulding (137), repeated in forest nurseries in 1907 by Jones (83) and Spaulding (136). Most of the experiments with these two substances have already been summarized (67). A report not mentioned in this summary is that of Schaaf (119, p. 88), who obtained favorable results with the acid. The great trouble with formaldehyde is its tendency to kill dormant seed. The length of time which must be allowed to elapse between treatment and sowing in order to avoid this killing varies with conditions. Formaldehyde is more expensive than acid and seems on the whole to have been less effective in disease control. Acid, on the other hand (applied just after the seed is sown, which is found to be the best time), on a few soils has caused injury to radicles, which it was at first thought could be prevented only by very frequent watering during the germination period; while in a few cases, when cold

weather resulted in a long germination period, it has killed or inhibited the germination of some of the dormant seed. All injury can be prevented by treatment a few days before sowing, followed by the addition of lime just before sowing, but lime used in this way has apparently destroyed a considerable part of the value of the acid treatment against the disease. Further consideration of the data on which earlier papers (63, 67) were based indicates that the apparent need for frequent watering during the germination period, which was required at a few of the nurseries where the first tests of acid treatment were made, as well as practically all of the germination reduction, was due to the use of unnecessarily large applications of acid and that the trouble can be eliminated by determining by test the minimum quantity of acid which will be reasonably effective in each locality. If this can be done it should establish the acid treatment as the most profitable for general use of any of the methods of damping-off control which have so far been extensively tested.

In view of the various parasites which may cause damping-off at different times and places and which vary greatly both in their means of dissemination and in their physiological qualities, it is not believed that any single disinfectant will be found entirely satisfactory at all nurseries. It is also unfortunately true that no one strength of treatment can be recommended for all nurseries. The quantity of acid to be used at any specified nursery will have to be determined by test at that nursery. A single test, no matter how well conducted, is not sufficient to serve as a basis for conclusions. However, a number of small-scale tests, made at different times and in different parts of the seed-bed area, should determine the best treatment for any particular nursery with a reasonable degree of certainty and with very little work. If the plats are equal in size and receive equal quantities of seed, all the nurseryman needs to do to determine the value of the treatments is to count the number of living seedlings on the different plats at the end of the season. The decrease in the number of weeds as a result of the use of acid is itself sufficient at a number of nurseries to pay the entire cost of the treatment. Detailed methods of application have already been published (67). The differing proportions of acid between which the best treatment will ordinarily be found to lie are 2 and 7 c. c. (one-sixteenth and one-fourth of a fluid ounce) of the concentrated commercial acid per square foot of seed bed, applied just after the seed is sown and covered. It should be dissolved in 500 to 1,000 c. c. (1 to 2 pints) of water per square foot of bed before applying. The drier the soil before treatment, the more water should be used in dissolving the acid.

No treatment applied after germination begins can have the maximum value in controlling the disease, because the damping-off para-

sites frequently, if not usually, do part of their work before the seedlings appear above the soil. Furthermore, any treatment at all effective against the disease is almost certain to hurt the seedlings if applied after the seed starts to sprout.

Both the acid and copper-sulphate treatments which have been found useful in pine seed beds are of very doubtful value for most hosts other than conifers, as the angiosperms on which observations have so far been made are too easily injured by the disinfectants. The weeds in the nurseries have been injured or entirely kept from appearing by treatments which caused no injury to the pines.

CAUSAL FUNGI.

CORTICIUM VAGUM.

Occurrence and parasitism.—In a recent publication (68) *Corticium vagum* B. and C. (*C. vagum solani* Burt, *Hypochnus solani* Pril. et Del., the common damping-off Rhizoctonia) has been reported on a number of conifers. Inoculation, reisolation, and reinoculation on pine have established its parasitism on this host beyond a reasonable doubt, though in these inoculations, as in most, if not all, the work which has been done with the fungus on angiospermous hosts, the cultures employed have been from plantings of diseased tissue instead of from single spores. The inoculation experiments have confirmed the field observations indicating that this fungus is fully as able to cause loss by destroying germinating seed below the soil surface as to cause damping-off of the better known type after the seedlings appear above the soil surface.

An extensive list of angiosperms on which the fungus has been reported is given by Peltier (98). Cross-inoculations between the pines (68), on the one hand, and potato (40) and sugar beet (38) have shown the same strains to be parasitic on both conifers and angiosperms and established the physiological as well as the morphological identity of the fungus attacking pines with the common *Corticium vagum*. Now that Duggar (34) has offered strong, though not yet entirely conclusive, evidence of the identity of *C. vagum* with the European "vermehrungspilz" (the *Moniliopsis aderholdii* of Ruhland; 115) it is to be presumed that it is a cause of damping-off of conifers in Europe as well as in America, though no reports of it on conifers have been so far encountered in European literature. The Rhizoctonia reported by Somerville (132) on *Pinus sylvestris* and the *Rhizoctonia strobis* described by Scholz (121) as killing young *Pinus strobus* were both on trees more than 4 years old, so that they had no relation to damping-off. Furthermore, the first of these was apparently the old *Rhizoctonia violacea*, now known as *R. crocorum* (*R. medacaginis*), a fungus entirely distinct from *Corticium vagum*, probably belong-

ing to an altogether different group of fungi and not known to cause damping-off of any host. *Rhizoctonia strobil* is not sufficiently described to allow determination of its identity.

Variations in virulence.—In the inoculations earlier reported on conifers, different strains of *Corticium vagum* were said to vary greatly in virulence (68). Further examination of the data on which this statement was based yields confirmatory evidence. Part of this evidence is shown graphically in figures 1, 2, and 10. The experiments on which these graphs were based involved at the time of seed sowing the addition to the soil of apparently pure cultures of *C. vagum*. Throughout each experiment the different units received

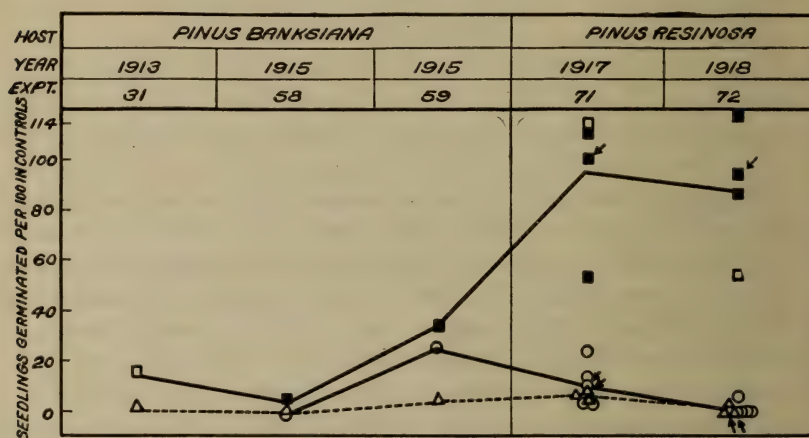


FIG. 10.—Diagram showing the relative activity of different strains of *Corticium vagum*, as indicated by the number of seedlings appearing in inoculated pots. Explanation of symbols: ○ = Strain 147, from spruce seedlings, Washington, D. C., 1910; ▽ = strain 213, from sugar beet seedlings, Washington, D. C., 1911; ■ = strain 230, from *Elaeagnus* sp., Kansas, 1913; □ = strain 233, from the same lesion as strain 230. Strains re-isolated from these, the results of which appear in experiments Nos. 71 and 72, are indicated by the same signs as the original strains used in the inoculations from which they were taken. The original strains in experiments Nos. 71 and 72 are indicated by arrows.

equal quantities of seed, and the culture substratum used in inoculating was the same for all strains. Experiments 36, 45, 47, 49, and 51 were conducted on plats in out-of-door drill-sown beds, experiment 36 on an alkaline soil, all of which had been heated in a moist condition at a temperature of not less than 80° C. for not less than 10 minutes,² and experiments 45, 47, 49, and 51 on a sand which had

² This temperature is probably high enough to eliminate damping-off organisms. Tests by Dr. Theodore C. Merrill indicate that the three most virulent parasites so far worked with are killed by placing agar tube cultures for 10-minute periods in water at the following temperatures: *Pythium debaryanum*, 65° C.; *Corticium vagum*, 50° C. for mycelium and 60° C. for sclerotia; *Fusarium moniliforme*, 70° C. Both the *Pythium* and *Fusarium* cultures contained spores. The possibility of the survival of oospores which would not be capable of germination for several months was apparently eliminated by the writer, who retained Dr. Merrill's heated *Pythium* tubes and made final transfers from them 7½ months after heating, still without securing growth. Plenty of typical oospores were present in the part of the heated culture from which transfers were made.

been treated with sulphuric acid followed later by lime. The other experiments included in the graphs were on autoclaved sandy loams in pots in the greenhouse. In these graphs are included all of the results in which the same groups of strains were used repeatedly in different experiments. In figure 1, the values plotted for experiments 36, 49, and 51 are for the number of seedlings which appeared above ground, the heavy inoculations and favorable conditions for damping-off in these experiments being such that even weak strains caused heavy losses and the survivals therefore do not give differential results. Comparison of the survival data in the other experiments in figure 1 with the emergence data for the same strains in that figure and in figure 10 indicates that the strains best able to reduce survival are also the ones best able to reduce emergence.

While the data presented in the graphs are not entirely consistent, it is very evident from them that strains 147, 213, and in a lesser degree 206 were regularly more virulent than most of the strains in tests conducted several years apart on different species of *Pinus*. It is also evident that certain strains of 186 and 189 which appear in figure 2 are quite regularly of low or doubtful virulence. Strains 50, 183, 192, 211, 212, 230, and 233, whose virulence is apparently intermediate, show a greater variability. In experiments 36, 45, 47, 49, and 51, in which conditions especially favor parasitism, they may cause practically as serious loss as the regularly virulent strains, the best differential results being shown in experiments in which the disease is less favored. The apparent variation in the relative virulence of such strains in different experiments may, of course, mean that their virulence is differently affected by different conditions. It seems rather more probable that the variation in relative activity is to be classed as accidental variation, necessarily great with small units which are subject to numerous uncontrollable variables. It seems entirely possible, however, that part of the observed differences in relative activity may be due to differences, not in virulence, but in the ability of the different strains to maintain themselves saprophytically in different soils during the period between inoculation and the commencement of germination. For example, strains 230 and 233 came from a nursery in southwestern Kansas in which the soil-acidity exponent, as determined by Dr. L. J. Gillespie, of the United States Bureau of Plant Industry, is 8.4. It seems entirely possible that these strains, rather strongly parasitic in some of the experiments, including an experiment on the soil from which they were taken, might prove less able than strains from some other habitats to maintain themselves on some of the eastern soils used in the greenhouse tests. The source of strains 230 and 233 was furthermore a locality where high soil temperatures are to be expected. The fact

that experiments 71 and 72, in which they showed the least virulence, were conducted in a colder greenhouse than any of the other tests may have had something to do with the lower activity indicated for these strains. Variation in the temperature requirements of different strains in accordance with the temperature of the source locality has already been demonstrated by Edgerton (35) for one of the anthrac-noses. It is hoped later to determine the temperature and acidity preferences of these two strains as compared with the others used. It should be noted that the consistently weak strain No. 189 (fig. 2), was abnormal in habit, lighter brown, and produced fewer sclerotia than typical strains. The other strains appearing in the graphs showed no conspicuous morphological or cultural differences that were identical. The only other strain which was noticeably abnormal in culture was one from pine seedlings in Kansas, intermediate in habit and color between No. 189 and the typical strains and indicating little more virulence than No. 189 in the few experiments in which it was used. It does not appear in figures 1 and 2, but was included in the experiments reported in the following paragraph. Peltier (99) believes low sclerotium-forming capacity to be a sign of degeneration and low virulence; the writer's experience agrees with his as to virulence, but these two strains showed no other evidence of lack of vigor.

As a further check on the reality of the apparent differences in virulence between different strains, all of the original strains available at the time, a total of 29, were used in the practically duplicate experiments 71 and 72 and the relative survivals of the same strains in the two series mathematically and graphically compared (fig. 11). The very decided correlation between the two experiments indicated by the graph has a coefficient³ of 0.813 ± 0.042 , nineteen times its

³The correlation coefficient, a very useful thing for many kinds of biological work, which unfortunately has received little attention from plant pathologists, is explained by Secrist (124, p. 43 et seq.) and the process of computation described (124, p. 453-467). A shorter method of computation is given by E. Davenport (30, p. 465-467); the example he gives is of a series with a large number of varieties, in which the correlation table is employed. Davenport's method is, however, just as useful in such a case as this, in which the number of varieties is too small to make the formal table advantageous. In such a case the computation should be arranged as by Secrist (124, p. 460-461), but the guessed rather than the true mean used and Davenport's formula employed. If the coefficient is +1, the correlation is perfect; if it is 0 there is no correlation, and if -1, perfect negative correlation. The significance of a coefficient less than 1 is judged from its relation to its probable error. King (84), in an excellent discussion of correlation, gives rules for judging the degree of significance of the coefficient. The correlation coefficient has its greatest potential usefulness in examining apparent causal relations. It is so used in connection with the relation between the hydrogen-ion exponent and damping-off in considering figure 12 of the present bulletin. Interexperimental, or, as Harris calls them, "interannual" correlation coefficients of the sort used for these Corticium strains have been used by Norton (96, p. 51) in measuring the constancy of rust resistance of asparagus strains, by Harris (54) in demonstrating the constancy of differences in various characters between strains or individuals, and they appear to be useful for this purpose in the present case.

probable error. Peltier's results permit similar correlations for the 18 strains common to his experiments 1 and 1A on carnation cuttings and for the 22 strains common to experiment 1 on cuttings and experiment 2 on seedlings. The coefficients found are decidedly lower than those obtained from the experiments on pine, 0.51 ± 0.117 for the experiments on cuttings and 0.36 ± 0.124 for the comparison of the results on cuttings with the results on seedlings, but nevertheless indicate some interexperimental correlation for the same strains and therefore inherent differences in parasitic ability between the different strains.

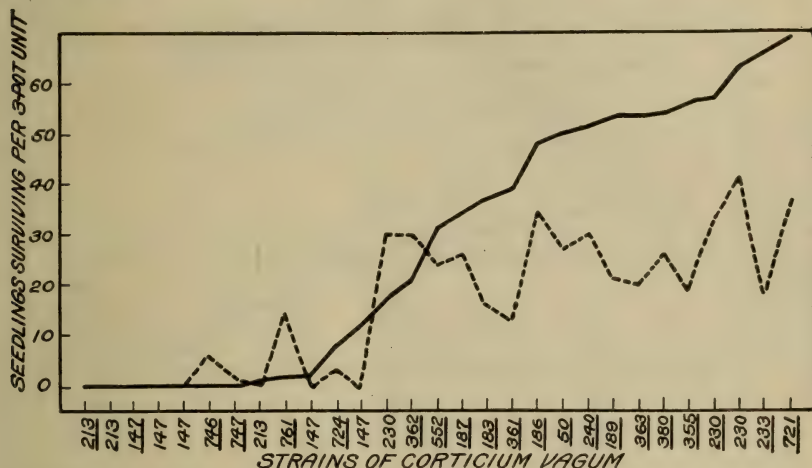


FIG. 11.—Diagram showing the comparative virulence of 29 strains of *Corticium vagum* in two successive inoculation experiments on *Pinus resinosa*. The results in experiment No. 71 are shown by the solid line, the strains being arranged from left to right in the order of descending virulence indicated by the number of seedlings surviving in this experiment. The results from the use of the same strains in experiment No. 72 are shown by the broken line. The obvious correlation between the two curves (coefficient 0.81 ± 0.04) indicates a real difference in virulence between the different strains. The strains indicated by the underscored numbers are original strains and those not underscored reisolations from the original strains in earlier inoculation experiments on pine seedlings.

In the work on pine seedlings, with the possible exception of strains 230 and 233, there was no evidence of attenuation in artificial culture. Strains 147 and 213, isolated in 1910 and 1911, respectively, seemed as strongly parasitic in experiments 71 and 72 (1917 and 1918) as any of the five strains isolated in 1916 or the six strains isolated in 1915.

Of the 20 strains above mentioned, three pairs were isolated under such conditions and showed such later agreement in performance as to indicate their individual identity. For the purposes of consideration in the following paragraph, the one of these probably duplicate strains which happens to have the higher number was eliminated from each pair. The survival figures in pots inoculated with the 17 strains

remaining, giving the mean of the results in experiments 71 and 72, are shown graphically in figure 13, together with the results of some of Peltier's experiments in which other strains were used. Percentages of seedlings damped-off after germination are not included in these and most of the other data on pines because the most virulent strains often entirely prevent germination, and no value for subsequent loss is obtainable. The grouping of most of the writer's strains at the least virulent end of the register (that is, the one with the highest number of living seedlings) is of some interest. The distributions based on the two experiments considered separately

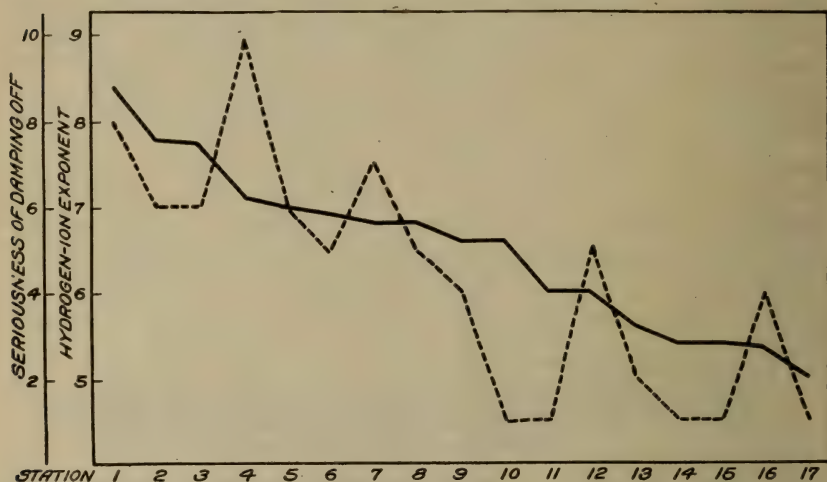


FIG. 12.—Diagram showing the relation between damping-off of conifers (broken line) and soil acidity (solid line). The acidity of soil samples from the different nurseries, determined by Dr. L. J. Gillespie, is reported as P_{H7} , indicating approximate neutrality while P_{H6} indicates ten, and P_{H5} one hundred times as great a hydrogen-ion concentration as P_{H7} ; therefore the lower the hydrogen-ion exponent line, the greater the acidity. The seriousness of damping-off at each nursery is on an arbitrary scale in which nurseries with negligible loss are rated as 1, and the nursery which suffered most is rated as 10. These values are estimates, though for some of the nurseries extensive counts were available on which the estimates were based.

agreed very well in this grouping. The minor group at the end of extreme virulence is not taken to indicate an actual grouping but, rather, an artificial one, due to the fact that both the strongest strains and some less strong were thrown into the same group by the lack of additional seedlings for the stronger strains to kill. This lack of additional seedlings constituted a limiting factor. In other words, conditions favored damping-off even in these two experiments too much to permit completely differential results for the more virulent strains. Despite this artificial limit preventing the full variability becoming evident, the coefficient of variability of the survivals

had the high value of 63 ± 9.7 per cent. The graph indicates also a decided, though less extreme, degree of variability for Peltier's strains on carnations; the survivals for the 18 strains which he used in both of his experiments on cuttings have a variability coefficient of 29 ± 3.5 per cent and the 23 strains in experiment 2 on seedlings 55 ± 6.9 per cent.

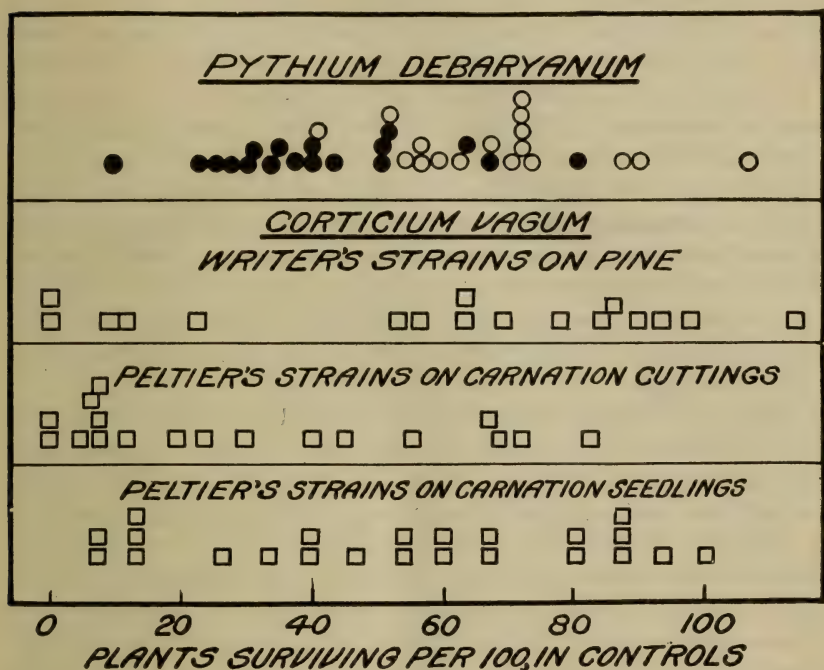


FIG. 13.—Diagram showing the results of inoculations with 17 strains of *Corticium vagum* and 35 strains of *Pythium debaryanum*, arranged in decreasing order of virulence from left to right, as indicated by the survivals in pots of pine seedlings artificially inoculated with them. The *Pythium* results represent the mean survivals in 5 pots inoculated with each strain in each of experiments Nos. 66, 67, and 68. Each point located is therefore based on the results in 15 pots, 10 of *Pinus banksiana* and 5 of *P. resinosa*. The *Corticium* results on pine represent 5 or 6 pots each, in two experiments (Nos. 71 and 72) on *P. resinosa*. The outline circles represent *P. debaryanum* strains from East Tawas, Mich.; the solid circles represent strains from other localities. The second row of squares shows the sum of the results in Peltier's experiments Nos. 1 and 1a (99, his table 3). The lowest row of squares shows his results in experiment No. 2 (his table 4).

The strains represented in figure 13, as used on pine, include 1 from bean, 2 from potato, 1 from sugar beet, 1 from *Elaeagnus*, 2 from *Picea engelmanni*, and 10 from *Pinus resinosa*, *P. ponderosa*, and *P. banksiana*. Two were from Washington, D. C., 2 from New York, 1 from Ohio, 4 from Michigan, 4 from Minnesota, 1 from Nebraska, 2 from Kansas, and 1 from California. The sources of these strains are widely distributed both as to host and locality; they are

rather more representative of the country as a whole geographically than the strains in the larger of Peltier's experiments, though less representative as to host sources. The number is too small to justify conclusions as to the proportion of *Corticium vagum* strains which can be expected to prove strongly virulent on pine. The data are offered merely as a beginning, to which it is hoped experimenters with other strains of *C. vagum* will make additions.

In addition to the strains used in these two experiments, several others which had been lost or for other reasons could not be included in both the final experiments had been previously tested on pines in earlier experiments. Of these, 6 strains, 1 each from alfalfa, sugar beet, *Pseudotsuga taxifolia*, *Pinus banksiana*, *P. resinosa*, and *P. strobus*, gave indications of low virulence on the pines; 3 strains, 1 each from sugar beet, *Pinus sylvestris*, and *P. ponderosa*, gave indications of rather high virulence; while another strain from *P. ponderosa* indicated an intermediate ability to attack pine. Combining these strains with those represented in figure 13, there are data on 27 original strains, of which 8 are roughly classed as strongly virulent on pine seedlings, 14 as weak, and 5 as intermediate.

Edson and Shapovalov (40) have conducted inoculation experiments on potato stems with 6 of the *Corticium* strains which had been used on pine, including the 5 strains mentioned by them on page 218 and their strains R. XV (the writer's strain 192 of fig. 2) on page 215. Strains 147 and 724, which had proved the most destructive in the inoculations on pine, appeared also rather strongly virulent on potato. Strain No. 186, originally from potato, which had given no definite evidence of parasitism on pine, also proved unable to cause lesions on the potato stems. The remaining 3 strains, all of intermediate virulence on pine, gave results on potato which were less indicative of agreement with the order of virulence on pine. The data suggest that strains strongly parasitic on potato are likely to be strongly parasitic on pine, and vice versa, but the agreement between their results and the writer's is not sufficiently complete to establish the point.

FUSARIUM SPP.

Fusarium is often found on or in damped-off seedlings (24, 46, 60, 94, 120, 137, 141, 142). The early inoculation experiments, conducted in the main with strains not sufficiently described to allow their identification, have been recently summarized (68, p. 537), together with descriptions of inoculation experiments on pine seedlings with four commonly recognized species of *Fusarium*. These, though not followed by reisolation, gave rather definite evidence that *Fusarium moniliforme* Sheldon was decidedly parasitic and *F. solani* less strongly so. *Fusarium ventricosum* Appel and Wollenw. was indi-

cated as more strongly parasitic than *F. solani*, but in a single test only and with a culture of doubtful purity. *Fusarium acuminatum* E. and E. gave no evidence of parasitism. These results agreed with those of Spaulding (137) in indicating that the ability to attack seedling conifers is not limited to a single species of *Fusarium* and that *F. moniliforme* is one of the more virulent. The statement by Hartig (61, p. 147-150) that a *Fusarium*-like fungus was able to corrode the young epidermis of pine seedlings has already been mentioned.

PYTHIUM DEBARYANUM.

Pythium debaryanum Hesse (*Artotrogus debaryanum* Atkinson, *Lucidium pythioides* Lohde) has been known since 1874 (74, 86) as a common cause of damping-off of various angiosperms. The first known observation was made by De Bary about 1864 (74). Despite the large number of hosts on which it has been listed, its parasitism has been definitely established on few. Peters (100) has successfully inoculated sugar beets with pure cultures; at least part of his strains, including presumably part or all of those he used in inoculation tests, were obtained from single spores. Edson (38) working with the same host, reisolated the fungus from inoculated seedlings, and made reinoculations with it. Both find it able to cause root sickness of plants not attacked early enough to be killed outright. Johnson (82) and Knechtel (85) have caused damping-off of tobacco seedlings with it, and the former reported it also able to persist in the cortex and kill the lower leaves of tobacco plants which survived attack. The fungus has long been reputed parasitic on potato tubers and has now been found by Hawkins (70) to be the chief cause of the rot known as "leak" in California. Peters (99) made successful inoculations with pure cultures on cuttings of *Pelargonium*. Most of the reports of parasitism, however, have been based on microscopic examination or more or less crude inoculation experiments. Noteworthy among the latter are those reported by Hesse (74) on *Camelina sativa* in the original description of the fungus. These were made before pure-culture technique had come into use with fungi, but were so thoroughly checked by microscopic observations at every step in the process that they must be admitted as very good evidence of the parasitism of the fungus. A number of reported angiospermous hosts are listed by Butler (23), Voglino (143), and Johnson (82, p. 34, footnote, and p. 35). Reinking (107) recently reported *Canica papaya* as attacked. A host which the writer has not found in the literature is rice, found by Dr. Haven Metcalf seriously attacked in the seedling stage in a field in South Carolina. A second apparently new host for the fungus is fenu-greek (*Trigonella foenum-graecum*). The writer found oospores typical of *Pythium debaryanum* in the tissues of damped-off seed-

lings received by Prof. William T. Horne, from Sonoma County, Calif., with the statement that the disease was seriously affecting the stand. The fungus was easily isolated, and the results of successful inoculations on pine with the cultures obtained are included in Table V (p. 47). A fungus resembling *P. debaryanum* was also found in damped-off cowpea (*Vigna* sp.) seedlings grown in rotation with pines at a Nebraska nursery.

Pythium equiseti Sadebeck, reported as parasitic on the prothallia of *Equisetum arvense*, was successfully used by Sadebeck (117) in crude cross-inoculations direct from *E. arvense* to potato tubers. De Bary (5) reversed the direction of the experiment between cryptogamous and phanerogamous hosts by successfully inoculating prothallia of *Equisetum arvense* with *Pythium debaryanum* directly from diseased *Lepidium* seedlings. He also secured positive results on prothallia of the fern *Todea africana* by the same method. The *Equisetum* prothallia he found to be especially favorable media on which to develop *Pythium debaryanum*. Fischer considers the fungus found by Bruchmann (17) and Goebel (49) on prothallia of *Lycopodium* sp. as probably identical with *P. debaryanum*. A careful reading of the original articles is sufficient to show that the symbiotic fungus which they described was an entirely different organism. *Saprolegnia schachtii* and *Sporodospora jungermanniae*, reported on two of the Hepaticæ, are of doubtful position (42, p. 403), though Butler (23, p. 89), after a survey of the literature, apparently favors the view that the former is distinct from the damping-off fungus. De Bary (5) reported *Vaucheria* and *Spirogyra* apparently immune against *P. debaryanum*.

Early references to *Pythium debaryanum* in connection with gymnosperms seem to have been based on the probability that it would be found to be the cause of damping-off in conifers (6; 97; 134, p. 27). The first actual finding of the fungus in any gymnosperms of which the writer is aware is indicated by a label marked *Pythium debaryanum* in the handwriting of Mrs. Flora W. Patterson on a package of coniferous seedlings from a New York nursery collected in 1904.⁴ The seedlings, judging from the several rather long cotyledons and the fact that both cotyledons and primary leaves are denticulate, are probably of one of the species of *Pinus* having medium-sized seed. In 1908 Dr. R. J. Pool, of the University of Nebraska, and his student, Mr. H. S. Stevenson, obtained in culture from damped-off coniferous seedlings a nonseptate fungus which was probably *Pythium debaryanum*, but which formed no distinctive spores on the media on which it was grown. A year later the writer obtained the fungus from pine seedlings at the same nursery and reported it as

⁴ In the Office of Pathological Collections, United States Bureau of Plant Industry.

parasitic on pines in preliminary inoculation experiments (62). In 1910 Spaulding (137) found it on spruce in New York, and Hofmann (76) later made successful inoculations on both pine and spruce seedlings, using *P. debaryanum* cultures both from aerial trap plates and from recently damped-off seedlings of cabbage, radish, and Russian thistle (*Salsola tragus*). Hofmann's work, detailed notes of which the writer has been permitted to examine, was done with cultures which were contaminated by molds, but was checked up by microscopic examination of the lesions resulting, which showed the affected tissues filled with nonseptate hyphæ. His results are taken as a rather strong indication that *P. debaryanum* attacks spruce as well as pine and that the fungus attacking conifers is physiologically as well as morphologically identical with that causing the damping-off of angiosperms.

There thus appears from the literature to be reason to believe that *Pythium debaryanum* is parasitic on representatives of two groups of the Pteridophyta and on gymnosperms, as well as on various monocotyledons and dicotyledons, a range of hosts not only remarkable but perhaps unequaled in our present knowledge of plant parasites. Final published proof of parasitism seems to be available for three or four species of dicotyledons only. Additional inoculations on conifers with strains isolated from various other hosts are reported in the present bulletin. Some of the detailed evidence necessary for complete proof of the parasitism of the *Pythium* on conifers, lacking in experiments previously reported because of the doubtful purity of the cultures used and failure to reisolate and reinoculate with the organism, is also given here, together with evidence of the ability of the parasite to cause root sickness of pines too old to suffer from damping-off.

Descriptive data of interest on *Pythium debaryanum* have been supplied by Hesse (74), De Bary (5), Ward (144), Miyake (89), Butler (23), and Butler and Kulkarni (24). An important contribution to the physiology of the fungus and the factors controlling its passage through the tissues of one of its hosts has recently been made in the previously mentioned paper of Hawkins and Harvey (71).

IDENTITY AND ISOLATION.

The fungus in the writer's cultures referred to *Pythium debaryanum* Hesse has been so called for the following reasons:

(1) The morphological characters agree with those described and figured for *Pythium debaryanum* by other workers and with those of strains obtained from Dr. H. A. Edson under this name.

(2) The absence of zoospores in the writer's cultures agrees with the experience of others with *Pythium debaryanum* (2, 5, 23, 24, 38, 100), all workers with pure cultures having obtained zoospores infrequently, if at all. The earliest work by Hesse (74) in which zoospores were apparently produced

readily at certain times of the year was done before the development of pure-culture methods. Water cultures kept in the dark and in the light, at constant and at varying temperatures, with nutrient substrata consisting of steamed or autoclaved fragments of potato, carrot, sweet potato, turnip, sugar beet, corn meal or rice, nutrient agar, sugar-beet seedlings, and insects have all produced only sexual fruiting bodies and chlamydospores (the so-called conidia).

(3) The successful cross-inoculations, those which Edson (38) used on sugar-beet strains and the writer had found parasitic on pine and had used on pine, strains which Hawkins had found parasitic on potato tubers and Edson on sugar beets, confirm the work of Hofmann (77) in indicating that the *Pythium* which causes the damping-off pine is a parasite on entirely unrelated species of host plants, a commonly recognized characteristic of *Pythium debaryanum*.

The organism is easily isolated from recently damped-off coniferous seedlings or from soil direct by placing the seedlings or a lump of soil at the edge of a Petri dish of solidified prune agar and transferring to tubes mycelium from the advancing edge of the resulting growth. It has been found in or obtained from damped-off conifers in California, Kansas, Nebraska, Minnesota, and the District of Columbia, as well as in cultures made by Mr. Glenn G. Hahn in Michigan. *Picea engelmanni*, *P. sitchensis*, *Tsuga mertensiana*, *Pinus nigra austriaca*, and *Pseudotsuga taxifolia* are the coniferous hosts from which cultures of *Pythium debaryanum* have been obtained. It has been isolated directly from soil not only in coniferous seed beds but from open grassland in California not adjacent to any seed bed or cultivated crop. Unless *Mucor* is abundant, *Pythium* is commonly obtained in apparently pure condition on the first transfer from the plate, as prune agar appears unfavorable for most bacterial growth while allowing rapid spread of the *Pythium*. On media made from prunes which taste sweet and with a total gross weight of not more than 40 or 50 grams per liter of medium, the *Pythium* will make a rapid growth, often extending radially 1 mm. per hour at temperatures in the neighborhood of 22° C. and produce both chlamydospores and oospores. A less valuable medium for isolation work, but more convenient for subcultures than any other which has been tested, is autoclaved corn-meal agar. The growth is not luxuriant, but spores are always formed and the cultures seem to be as long lived as those on any other medium, retransfer being rarely necessary more often than twice a year. Much stronger growth and more abundant fruiting is obtained on such media as sugar-beet or rice-stem agar, but the leathery surface of the culture on such media makes transferring difficult. On rice grains, corn-meal mush, beef agar, and on corn-meal agar plus 2 per cent dextrose or sucrose no spores are formed and the cultures are short lived, though growth is heavy and on the last-named medium extremely rapid. On agar containing the juice from sour prunes or on corn-meal agar prepared without subjecting it to the high temperature of the autoclave, both growth and fruiting have been very poor or even lacking.

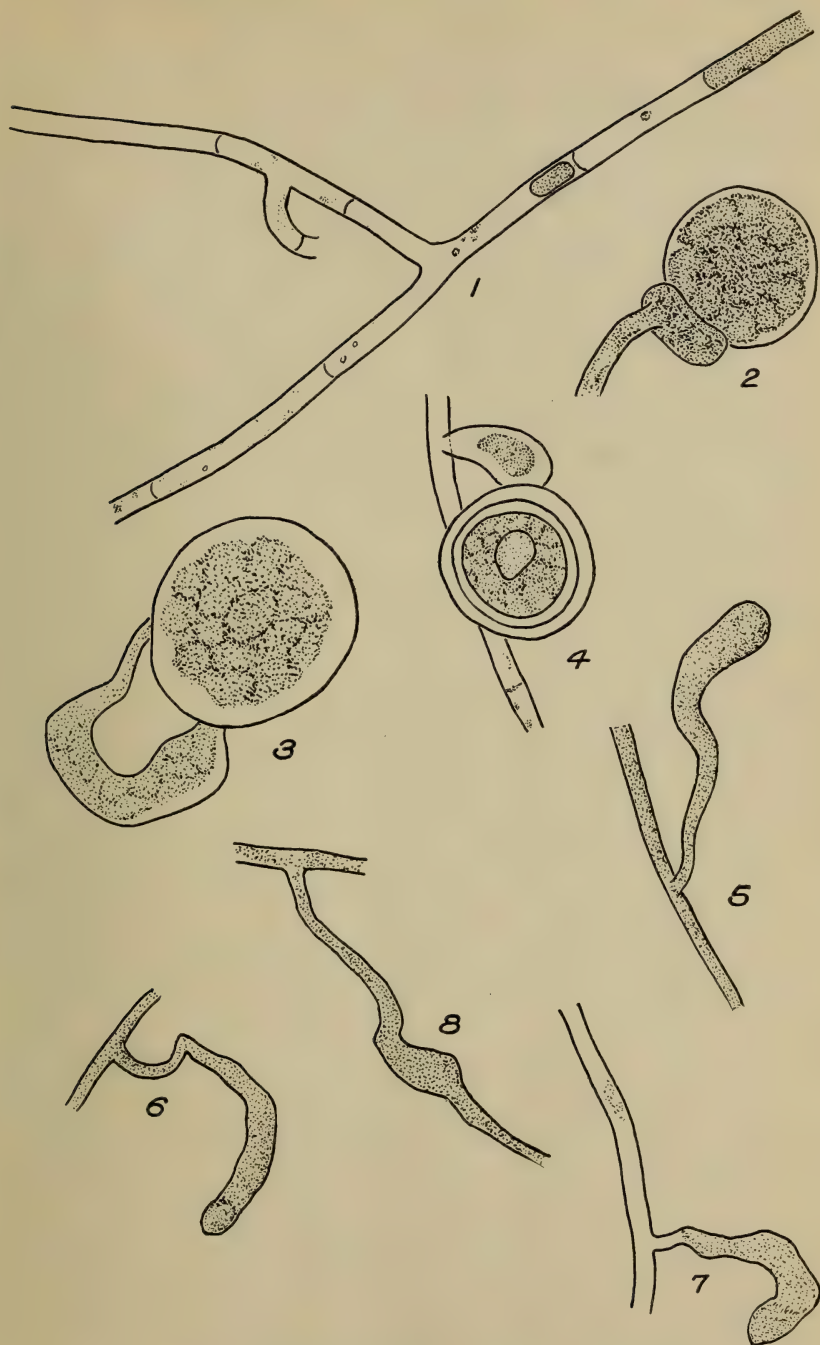
In both artificial cultures and in the tissues of coniferous and dicotyledonous hosts the numerous strains observed showed no conspicuous differences in the size or other characters of the spores produced, though noticeable and constant abnormality was found in one strain in the readiness with which spores were produced and in two strains in the ratio between chlamydospores and oospores in agar cultures. In the first-mentioned strain, obtained from pine in Kansas, and in cultures reisolated from seedlings inoculated with it, both chlamydospores and oospores are produced tardily and so scantily that it is often difficult to find them. In most strains, on the other hand, almost the entire contents of the mycelium are promptly emptied into the spores as soon as the limits of rapid vegetative growth are reached. In another abnormal strain from pine from the same locality, and in still another furnished by Hawkins from a California potato, chlamydospores are produced in large numbers, but oospores are few. In many other strains, including several from California, the opposite condition obtains, oospores in plate cultures being decidedly more numerous than chlamydospores. These peculiarities of particular strains seem to be fairly constant characters, the first abnormal strain mentioned having been under observation for more than three years without any change in its tendency to scanty fruiting, and the low ratio of oospores to chlamydospores having been constant during the shorter periods over which the observation of the other strains extended. In view of the small variation between different strains in the matter of speed of growth, a purely vegetative character, this variation in reproductive habit is somewhat surprising. The strain which produced spores infrequently was unquestionably parasitic, though it killed fewer seedlings than the average *Pythium debaryanum* strains. The strains with the high ratio of chlamydospores were both of at least average virulence on pine.

Oospores in the strains the writer has had in culture, whether examined in agar, in water cultures, or in root tissues, have ordinarily been somewhat larger than the diameter of 14 or 15 to 18 μ given in a number of the descriptions. The maximum range has been 12.8 to 20.6 μ , the same strain sometimes being well down within the usual size range and sometimes ranging from 17 to 20 μ . The largest oogones observed were 26 μ in diameter. Various stages of fertilization are shown in Plate I, figures 2 to 4. Chlamydospores attain a maximum diameter in the case of the limoniform intercalary forms of 32 μ , and spherical chlamydospores sometimes reach a diameter of 28 μ . There is no lower limit for these bodies, as under unfavorable conditions—e. g., in sour-prune agar—they are sometimes all less than 15 μ in diameter, and the smaller ones are little larger than the

hyphæ which bear them. Both oogones and chlamydospores may be either terminal or intercalary.

The normal hyphæ are large, varying from 3 to 7 μ and sometimes more in diameter. Typical hyphæ, showing the false septa developed at the boundary of the protoplasm and the portions of the hyphæ which have been evacuated in the extension of the younger parts, are shown in Plate I, figure 1. At points at which the ends of hyphæ come in contact with the glass of the culture dish, peculiar contact swellings are produced (Pl. I, figs. 5 to 7), much the shape and size of antheridia, but not walled off from the adjacent hyphæ and having no apparent significance in the life history of the fungus. These are not always terminal (Pl. I, fig. 8). It is noteworthy that Hesse described contact swellings at the tips of the hyphæ just before penetrating the epidermis of *Camelina sativa*.

The asexual nonsporangial fruiting bodies of *Pythium debaryanum* are referred to as chlamydospores rather than as conidia, though in most of the previous literature the latter term has been used for them. Hesse called the terminal bodies conidia and the intercalary, gemmæ (74). It is believed that the best terminology and the one which should be followed for all fungi, as it now is for most, is that which limits the term conidium to a spore which is adapted primarily for aerial distribution or which is at least readily separated as soon as it is mature from the parent hypha from which it arises. The most typical conidium, in fact, is a spore which is abstricted by the parent hypha at maturity. The asexual spores of this *Pythium* remain attached to the parent hyphæ indefinitely even after the hyphæ are dead and empty. It is a common thing to find numbers of these bodies in water cultures, still attached to hyphæ which are so completely empty that it is only with favorable lighting that their thin colorless walls can be seen. So firm is the attachment that vigorous shaking is required to release any considerable proportion of the spores. It seems probable that in nature the spores are released chiefly as a result of the destruction of the hyphæ walls by bacteria. While there is reason to think that *Pythium debaryanum* is sometimes disseminated by wind, it is by no means certain that it is through the medium of these spores. It is true that these bodies have thinner walls than are commonly found in chlamydospores of some other fungi, but they have somewhat thickened walls as compared with the vegetative hyphæ, and they are commonly intercalary. These facts, and the indications that they are better able to withstand unfavorable conditions than are the hyphæ, all tend to entitle them to rank as chlamydospores. De Bary (5) speaks of them as "dauerconidia." Their ability to stand drying is not entirely demonstrated, but is indicated by the relative longevity of the fungus on different media. On beef agar and on rice, on which no spores are



PYTHIUM DEBARYANUM FROM ARTIFICIAL CULTURES.

FIG. 1.—Hyphæ, showing old portions of hyphæ and false septa separating them from the portions still containing protoplasm. FIGS. 2 to 4.—Various stages of oospore formation. FIGS. 5 to 8.—Hyphal swellings at points of contact with glass. From camera-lucida drawings.

formed, a few tests indicate that the fungus is very short lived, sometimes dying in a month. On media on which spores are produced, transfers any time before the sixth month, and often as late as the tenth month, start immediate growth on fresh media. This is true even for strains which produce few or no oospores. The immediate commencement of growth from cultures 3 or 4 months old is taken as an indication that the new growth results from the asexual spores, as oospores are commonly believed to require a resting period of five or more months before they are able to germinate (5, 38).

INOCULATION ON STERILIZED SOIL.

Pythium debaryanum has been used in inoculation in pots of recently autoclaved soil in 16 different series of tests. In 10 of these, fragments of agar cultures were scattered over about one-fourth of the area at the side of each pot when seed was sown; in 2 of these 10 and also in 2 other tests some pots were inoculated over their entire surface. In every one of these 12 heavily inoculated series positive results were indicated by smaller emergence and where any considerable number of sprouting seeds escaped the fungus by heavier damping-off loss in the inoculated pots than in the controls. In some cases the fungus killed all or practically all of the seed or seedlings in the inoculated pots before they emerged from the soil.

In a total of 7 series, part or all of the pots received lighter inoculations, consisting of one or two small fragments of an agar culture placed just below the surface of the soil at the edge of each pot. In 5 of these success was indicated. In the sixth and seventh also of these lightly inoculated sets, there was more damping-off in the inoculated pots than in the controls, but the difference was negligible. The damping-off caused by light inoculations was in general distinctly less than that resulting from broadcast inoculations. To sum up the evidence: Sixteen separate experiments were conducted with *Pythium debaryanum* on pine seedlings in autoclaved soil, and in every one fewer seedlings survived in the inoculated pots than in the checks; the difference in most of the experiments was large.

Of the successful inoculation experiments—that is, those in which the difference between the inoculated pots and the checks seemed significant—9 series included jack pine (*Pinus banksiana*), 7 series western yellow pine (*P. ponderosa*, Colorado and New Mexico seed), and 3 series red pine (*P. resinosa*). In addition to the pines, Douglas fir (*Pseudotsuga taxifolia*, Colorado seed) was grown in two large plats in one of the earlier series, one being inoculated over its entire surface with *Pythium debaryanum*. Because of the poor quality of the seed in the test on Douglas fir, too few seedlings were obtained to furnish a decisive test, but the difference in the emergence in the inoculated plat and the control affords preliminary evidence that

Pythium can cause the "germination-loss" type of damping-off in Douglas fir as well as in species of *Pinus*. Of the seeds sown in the control plat 43 produced seedlings which appeared above the soil, while only two seedlings appeared from an equal number of seeds sown in the inoculated plat.

Altogether, 38 strains, excluding reisolations, have been tested on one or more of the 3 pine species. Strains from both the Pacific coast and the eastern United States and from a number of hosts other than pines were among those used. With the exception of two or three strains from a pine nursery in Michigan, the use of which was followed by so little damping-off as to leave their parasitism uncertain, all of the strains proved parasitic under favorable conditions, though some were more virulent than others. The positive results in the 14 successful experiments are based on the comparison of a total of approximately 1,160 inoculated pots with 195 control pots.

TABLE III.—*Inoculation experiments with Pythium debaryanum in pots of sterilized soil.*

Series, experiment number, and host.	Pythium strain.		Num- ber of pots.	Inoculation method.	Results.		
	No.	Initial strain from which it was reisolated.			Emerged (per 5-pot unit).	Damp- ing-off after germi- nation (per cent).	Sur- vival (per 5 pot unit).
SERIES A.—Initial inocula- tions:							
No. 58, <i>Pinus banksiana</i> ..	218.....		5	Agar cultures broadcast at one side of pot.	1	100	0
	Controls.....		5	No inoculum	74	0	74
	..do.....		5	..do.....	82	0	82
No. 58, <i>Pinus ponderosa</i> ..	295.....		5	Agar cultures at single point in each pot.	41	28	30
	Controls.....		5	No inoculum	55	0	55
	258.....		5	Agar cultures broadcast at one side of pot.	16	81	3
No. 62, <i>Pinus banksiana</i> ..	..do.....		5	..do.....	18	89	2
	Controls.....		5	No inoculum	90	0	90
	..do.....		5	..do.....	82	0	82
	..do.....		6	..do.....	82	0	82
	338 ^a		5	Agar cultures broadcast at one side of pot.	14	72	4
	347 ^a		5	..do.....	3	67	1
	348 ^a		5	..do.....	13	67	4
Control ^a			5	No inoculum	78	0	78
SERIES B.—Reisolated strains:							
No. 62, <i>Pinus banksiana</i> ..	338.....	No. 295 (in <i>P.</i> <i>ponderosa</i> , expt. 58).	5	(b)	14	72	4
	Controls.....		5	.....	78	0	78

^aA different soil used in these pots from that used with strain 258 and the first three control units.

^bAll inoculations with fragments of agar cultures scattered broadcast at one side of the pot, including about one-fourth of its area. Nothing was added to the controls in experiment 62, but sterile agar was added to the controls in experiments 66, 67, and 68.

TABLE III.—*Inoculation experiments with Pythium debaryanum in pots of sterilized soil—Continued.*

Series, experiment number, and host.	Pythium strain.		Number of pots.	Inoculation method.	Results.			
	No.	Initial strain from which it was reisolated.			Emerged (per 5-pot unit).	Damp- ing-off after germi- nation (per cent).	Sur- vival (per 5- pot unit).	
Series B.—Reisolated strains—Continued.								
No. 66, <i>Pinus banksiana</i> ..	338.....	No. 295 (in <i>P. ponderosa</i> , expt. 58).	5	(a)	9	67	3	
	345.....	No. 218 (in <i>P. banksiana</i> , expt. 58).	5	(a)	15	33	10	
	414.....	No. 258 (in <i>P. banksiana</i> , expt. 62, 2d unit).	5	(a)	36	25	27	
	415.....	do.....	5	(a)	59	10	54	
	419.....	No. 348 (in <i>P. banksiana</i> , expt. 62).	5	(a)	25	100	0	
	450.....	No. 347 (in <i>P. banksiana</i> , expt. 62).	5	(a)	41	72	11	
	Controls.		25	-----	75	14	64	
	338.....	No. 295 (in <i>P. ponderosa</i> , expt. 58).	5	(a)	7	57	3	
	345.....	No. 218 (in <i>P. banksiana</i> , expt. 58).	5	(a)	24	37	15	
	414.....	No. 258 (in <i>P. banksiana</i> , expt. 62, 2d unit).	5	(a)	57	24	44	
	415.....	No. 258 (in <i>P. banksiana</i> , expt. 62, 1st unit).	5	(a)	30	37	19	
	419.....	No. 348 (in <i>P. banksiana</i> , expt. 62).	5	(a)	62	65	22	
No. 67, <i>Pinus banksiana</i> ..	450.....	No. 347 (in <i>P. banksiana</i> , expt. 62).	5	(a)	53	27	39	
	Controls		23	-----	87	5	83	
	338.....	No. 295 (in <i>P. ponderosa</i> , expt. 58).	5	(a)	85	26	63	
	345.....	No. 218 (in <i>P. banksiana</i> , expt. 58).	5	(a)	76	24	58	
	414.....	No. 258 (in <i>P. banksiana</i> , expt. 62, 2d unit).	5	(a)	98	14	84	
	415.....	No. 258 (in <i>P. banksiana</i> , expt. 62, 1st unit).	5	(a)	92	11	82	
	419.....	No. 348 (in <i>P. banksiana</i> , expt. 62).	5	(a)	95	45	52	
	450.....	No. 347 (in <i>P. banksiana</i> , expt. 62).	5	(a)	84	40	51	
	Controls		18	-----	104	0	104	
	No. 68, <i>Pinus resinosa</i>							

^a All inoculations with fragments of agar cultures scattered broadcast at one side of the pot, including about one-fourth of its area. Nothing was added to the controls in experiment 62, but sterile agar was added to the controls in experiments 66, 67, and 68.

As has been stated, securing positive results did not always mean that the control pots remain uninfected. Even with the most careful treatment and the use of boiled water throughout the experiment

it proved difficult to keep the control pots entirely free from damping-off. Cultures from seedlings which damped-off spontaneously in control pots indicated that *Pythium* as well as *Fusarium* may be introduced by accident, even when insects, birds, and rodents are excluded. This agrees with the evidence of Hofmann (77) that *Pythium debaryanum* is sometimes disseminated by wind, despite its apparent lack of adaptation to wind distribution. It is also indicated, however, that unheated tap water increases damping-off when used on control pots and probably carries this semiaquatic fungus. Notwithstanding infections in the controls of a number of the experiments, it is believed that the large number of pots whose results have been considered in drawing conclusions, the fact that the *Pythium* pots lost more heavily than the controls in every one of the 16 experiments, and the magnitude of the differences between both the emergence and subsequent damping-off figures for the inoculated pots and the controls in most of the experiments establish the parasitism of the fungus in inoculation on autoclaved soil without it being necessary to present all the evidence in detail. The pot series which involved reisolation and reinoculation (Table III), together with the results given for other purposes in Tables V and VI, seem sufficient by themselves to establish a parasitic relationship.

REISOLATION AND REINOCULATION.

In a number of the experiments dead seedlings in the inoculated pots were examined and typical *Pythium* hyphæ and spores were found. In three of the experiments in which the controls remained entirely free from disease up to the time the experiment was closed, reisolations and reinoculations were made in accordance with the usual rules of proof. The results are given in Table III.

From Table III it will be seen that five strains reisolated from *Pinus banksiana* and one strain reisolated from *P. ponderosa* gave positive results in pots of *P. banksiana* and *P. resinosa*. In addition to the reinoculations shown in the table, the strain reisolated from *Pinus ponderosa* (No. 338) was again reisolated in duplicate from *P. banksiana* in experiment 62, and both these secondary reisolations gave cultures which were parasitic on *P. banksiana* and *P. resinosa* in subsequent inoculations.

That the organisms reisolated were actually the same as those used in the initial inoculation is indicated not only by the absence of disease in the control pots of experiments 58 and 62, but by the distinctive characters of some of the strains. In general, cultures reisolated from strongly parasitic initial strains were themselves strongly parasitic and vice versa. This is shown by comparing the figures for the initial and reisolated strains, as shown in Table IV. Each figure represents the average results in 10 pots of jack pine and 5 of red

pine in experiments 66, 67, and 68 combined. The figures are relative, the mean survival of 47 different strains used in all three experiments being taken as 10. A survival figure above 10 therefore means that the strain was less destructive than the average *Pythium*, and a figure below 10 indicates more than average virulence. As strain 218 was not used in these three experiments, strain 345 can not be compared.

TABLE IV.—*Comparative virulence of original cultures and reisolated strains of Pythium debaryanum in experiments 66, 67, and 68.*

Pythium strain.	Description.	Relative survival.	Pythium strain.	Description.	Relative survival.
No. 258.....	Original culture.....	16	No. 409.....	Reisolated from 338.....	9
No. 414.....	Reisolated from 258.....	12	No. 347.....	Original culture.....	4
No. 415.....	do.....	12	No. 450.....	Reisolated from 347.....	7
No. 295.....	Original culture.....	4	No. 348.....	Original culture.....	10
No. 338.....	Reisolated from 295.....	4	No. 419.....	Reisolated from 348.....	4
No. 408.....	Reisolated from 338.....	6			

These figures are not absolutely consistent, but are to be viewed as contributing to the evidence furnished by the absence of damping-off in the control of experiments 58 and 62 that the cultures reisolated in those experiments were actually identical with the original strains. A further proof of this identity is in the fruiting tendencies of the strains. Both Nos. 414 and 415, the strains reisolated from original strain 258, exhibited the peculiarly sparse spore production which has been characteristic of strain 258 for the entire period during which it has been in culture. The other reisolated strains, taken from pots inoculated with normally fruiting strains, all showed normal spore production.

PURITY OF CULTURES.

A slight deficiency in the evidence as to the parasitism of *Pythium debaryanum* both in the writer's work and apparently in all previous investigations except those of Peters (100) and possibly Knechtel⁵ is the lack of single-spore cultures. The large number of strains which have remained apparently pure through numerous subcultures and have retained their individual characteristics as to virulence and fruiting tendencies (one strain having been carried on artificial media continuously for eight years without material change) give very strong justification for believing that the cultures used were pure. In three early inoculation tests the cultures used were afterwards found to have been contaminated by bacteria carried by mites; the positive results obtained in these three were the basis of the ear-

⁵ Knechtel's work in Rumanian has been available to the writer only in the German abstract, which makes an ambiguous statement on this point.

liest report of pathogenicity (62), but have not been used as evidence in the present bulletin, though the contaminating bacteria in one of them, when tested independently, showed no evidence of parasitism. In all the experiments mentioned in the foregoing as giving positive results with *Pythium* the cultures used were apparently pure.

Cultures from single chlamydospores should be reasonably easy to secure, part of the chlamydospores in water cultures being separable from the mycelium by vigorous shaking, and further inoculation tests with cultures so obtained are probably desirable. The experiments so far conducted are believed to be sufficiently conclusive, however, for all practical purposes. For isolation of absolutely pure lines of this or any other cenocytic fungus, it is evident, as pointed out by Dr. W. H. Weston (146), that isolations should be made from the uninucleate swarm spores. For the determination of the bare fact of pathogenicity such a refinement would be superfluous.

CROSS-INOCULATIONS.

The physiological identity of the *Pythium* attacking coniferous seedlings with the one which attacks dicotyledons is indicated by the results of several inoculation experiments. The last two experiments, one with jack pine and one with red pine for the host, are the most comprehensive and give results sufficiently decisive so that quotation of the corroborative evidence from earlier experiments is considered unnecessary. The results appear in Table V. Each unit consisted of five 3-inch pots except in the controls, in which 23 pots were used in the jack-pine experiment and 18 in that with red pine. In the second experiment, separate records were kept of the survival in each pot, and the probable error calculated from the controls was less than two seedlings per pot for a single pot, less than 0.9 for a mean of 5 pots, and less than 0.5 for the mean of the 18 control pots. While the number of controls was, of course, insufficient to furnish an exact basis for such a calculation, the small value found tends to confirm the impression gained from inspection of the table that considerable confidence can be placed in the results.

The difference appearing in Table V between jack pine and red pine in point of susceptibility to germination loss from *Pythium* agrees with field observations in Nebraska, the red pine at the Bessey Nursery, though on the whole more susceptible than jack pine to damping-off losses, having given indication of more resistance to the disease for the first week or two. Inoculations in other experiments on western yellow pine indicate that the strains which attack it are identical with those attacking jack pine and red pine.

The conclusion reached from the cross-inoculation results is that the *Pythium* causing damping-off of the three species of pine men-

tioned is identical with *Pythium debaryanum*, causing leak of potato tubers and the damping-off of seedlings of two dicotyledonous families.

TABLE V.—Results of inoculations on jack pine and red pine with *Pythium debaryanum* from various hosts.

Strain.	Host from which isolated.	Inoculation results.					
		On jack pine.			On red pine.		
		Emerged (per 5-pot unit).	Damp- ing-off (per cent).	Survival (per 5-pot unit).	Emerged (per 5-pot unit).	Damp- ing-off (per cent).	Survival (per pot).
	Dicotyledons:						
No. 131 <i>a</i>	Potato tuber	45	36	30	101	23	15.6
No. 810 <i>b</i>	Do.	45	34	30	62	41	7.4
	Average potato	45	35	30	82	32	11.6
No. 294 <i>c</i>	Sugar-beet seedlings	50	8	46	79	36	10.2
No. 295 <i>c</i>	Originally potato strain 131, but twice inoculated on and reisolated from sugar-beet seedlings by Ed- son	28	32	19	62	48	6.6
No. 296 <i>d</i>	Sugar-beet seedlings	19	32	13	68	58	5.8
	Average, sugar beet	32	24	26	70	47	7.4
No. 529	Fenugreek seedlings <i>d</i>	36	31	25	102	26	15.0
No. 530	Do.	60	49	31	108	22	16.8
	Average, fenugreek	48	40	28	105	24	16.0
	Conifers:						
No. 258	Western yellow-pine seedlings	58	9	53	109	17	18.0
No. 550	Sitka spruce seedlings	15	80	3	39	98	.2
No. 555	Engelmann spruce seedlings	42	29	30	45	70	5.0
	Average, spruces	29	55	17	42	84	2.6
	Controls	87	5	83	104	0	20.9

^a Furnished by Mrs. C. R. Tillotson; has been used successfully on sugar-beet seedlings by Dr. H. A. Edson.

^b Furnished by Dr. L. A. Hawkins; cause of leak.

^c Furnished by Dr. H. A. Edson.

^d Diseased material furnished by Prof. W. T. Horne.

VARIATIONS IN VIRULENCE OF PYTHIUM STRAINS ON PINE.

In *Pythium debaryanum* strains, as in the case of *Corticium vagum*, there appeared to be a considerable difference in the parasitic activity of different strains used in the same experiment. Figures 14, 15, and 16 show graphically the results from inoculations with different strains of *P. debaryanum* in all the experiments in which it was possible to compare directly the activity of different strains. All the inoculations involved at the time of sowing the addition to the soil of cultures on nutrient media in recently autoclaved 3-inch pots. In experiment 31C the inoculum fragments were scattered over the whole pot, in 31D at only one point in each pot, and in the others were distributed over about one-fourth of the pot's area. As noted elsewhere, the variations observed in the results may have been due in part to differences in the ability of the different strains to main-

tain themselves saprophytically in the soil used rather than entirely due to difference in virulence.

The data shown in figures 15 and 16 indicate in the first place rather more accidental variations in the results with *Pythium* than with *Corticium* (see figs. 1, 2, 10, and 11). The agreement between original and reisolated strains from the same original source is decidedly less good than in the case of *Corticium* (see experiments 71 and 72, figs. 10 and 11). In general, there are only two strains of

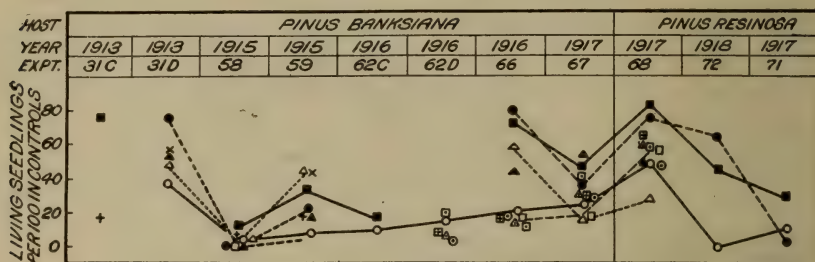


FIG. 14.—Diagram showing variations in virulence as indicated by the living seedlings in pots of autoclaved soil inoculated with different strains of *Pythium debaryanum*. For experiments Nos. 31 and 66 to 72, inclusive, the surviving seedlings at the end of two or three weeks after germination are shown. For the other experiments damping-off was so heavy in the inoculated pots that the survivals did not give differential results for the different strains, and the germinations are therefore shown. The reports are based for experiments Nos. 71 and 72 on 2 or 3 pots for each strain in each experiment, and for the other experiments on not less than 5 pots for each strain. In experiments Nos. 66, 67, and 68 the number of pots in each experiment for the strains whose reisolations were also used varied from 10 to 40 for each strain, the results of the separate 5-pot units being shown in figure 15. The strains indicated by the different symbols are as follows: *From potato*: ●=Strain 131, isolated in 1909, California. Furnished by Mrs. C. R. Tillotson. *From sugar beet*: ○=Strain 295 and its reisolations from pine. No. 295 was furnished by Dr. H. A. Edson as a reisolation of strain 131, after having been passed by him through two generations of sugar-beet seedlings. ▲=Strain 294, isolated in 1912. Furnished by Dr. Edson. △=Strain 296, isolated in 1912, Wisconsin. Furnished by Dr. Edson. ×=Strain 297, originally from pine, Nebraska, 1911. Passed through two generations of sugar-beet seedlings by Dr. Edson. *From pine seedlings*: + =Strain 255, Kansas, 1913. Chlamydospores numerous; oospores rare. ■=Strain 258 and its reisolations, Kansas, 1913. A sparsely fruiting strain. □=Strain 218 and its reisolation, Kansas, 1912. ○=Strain 347 and its reisolation, Washington, D. C., 1915. ◻=Strain 348 and its reisolation, Washington, D. C., 1915. △=Strain 349, Washington, D. C., 1915. ⊕=Strain 354, Minnesota, 1915.

Pythium which can be said to have definitely shown difference in activity continuing through several years and on different species of pine. These are strains 295 and 258. As No. 258, the weak strain, has also been found abnormal in its fruiting tendencies, the evidence in these graphs does not indicate a decided difference in virulence between different typical strains of *Pythium debaryanum*. The other strain, which seems rather uniformly weaker than No. 295, is No. 131, which according to Dr. Edson's records was originally the

same strain, No. 131 having been twice used in his inoculation experiments on sugar beets and strain 295 recovered from the second experiment. The apparent difference between this original strain and its supposed reisolation may possibly be due to the treatment given strain 131. Before it was used in any of the experiments shown but after it had been used by Dr. Edson, it was allowed to get very dry and was revived with great difficulty, growth being very slow. While it apparently recovered all of its normal growth qualities after one or two transfers, it is thought that this may possibly explain the apparently decreased virulence in the later experiments.

The failure to secure as definite indications of constant virulence differences as were obtained for several of the *Corticium* strains is believed to be in part due to a smaller actual difference between the different *Pythium* strains appearing in the graphs and in part to a larger accidental variation between results in pots inocu-

lated with the same strain. The growth of *Pythium* on agar media is much more affected by variations in the substratum than is the growth of *Corticium*, and it is rather natural to expect greater variations when the two fungi are added to autoclaved soil. In experiments 66, 67, and 68 a number of strains not used in the earlier experiments were tested, in addition to the strains previously used. The survival results for all the different strains, both original and reisolated, 47 in all, are shown graphically in figure 16. The results in experiments 66 and 67, both on *Pinus banksiana*, are averaged and taken as the subject, while the results with the same strains in experiment 68 are made relative and shown by the broken line. The correlation between the performance of the same strains on the two species of pine is by no means as clear in the graph as it was in the case of the *Corticium* strains (fig. 11). The areas bounded by the broken line and

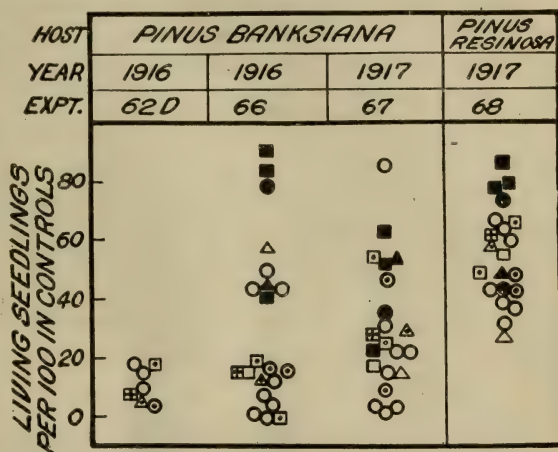


FIG. 15.—Diagram showing the results of inoculations with strains of *Pythium debaryanum*. This figure supplements figure 14, giving the results for original and reisolated strains independently. Each point plotted is based on the results in five pots. The object of this diagram is to give an idea of the degree of variability in the success of inoculations. An explanation of the symbols used will be found in the legend of figure 14.

the horizontal line showing the location of the mean for experiment 68 are much larger below the means than above it in the left-hand portion of the graph, while the reverse is true in the right-hand portion. To this extent the relative activity of the strains in this experiment agrees with the performance of the same strains in the two jack-pine experiments, as shown by the solid line. It can not be decided from an inspection of the graph whether there is a real agreement, in view of the large accidental variation present. However, the correlation coefficient, 0.446 ± 0.079 , five and one-half times its probable error, indicates a considerable correlation, not as good as was found for the *Corticium* strains, but sufficient to establish a strong presumption that observed differences in activity of the dif-

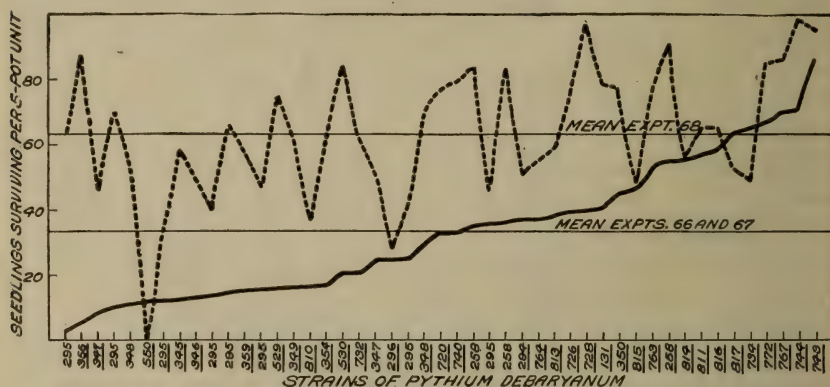


FIG. 16.—Diagram showing the comparative virulence of 47 strains of *Pythium debaryanum* in successive inoculation experiments on species of *Pinus*. The results in experiments Nos. 66 and 67 (on *Pinus banksiana*) are shown by the solid line, the strains being arranged from left to right in the order of descending virulence indicated by the number of seedlings surviving in those experiments. The results from the use of the same strains in experiment No. 68 (on *Pinus resinosa*) are shown by the broken line. Such correlation as there is between the two curves (coefficient 0.45 ± 0.08) goes to indicate a real difference in virulence between the different strains. The strains indicated by the underscored numbers are original strains, and those not underscored are reisolutions from the original strains in earlier inoculation experiments on pine seedlings.

ferent strains in these inoculation experiments were in part actually due to differences in the capacity of the strains.

It has been suggested in the foregoing that the difficulty in demonstrating constancy in the difference in virulence between the various strains of *Pythium debaryanum* is due in part to the lack of such extreme differences as were observed between the various *Corticium* strains. Figure 13 shows the distribution of the different original *Pythium* strains according to the virulence indicated in the three inoculation experiments of figure 16 (application to autoclaved soil at the time of sowing). Each value plotted is based on the average results in 15 pots. Of the strains used, 21 were from species of pine, 1 from spruce, 2 from potato tubers, 2 from fenugreek, 3 from sugar beet, and 6 from soil direct. Despite the considerable number of

strains, they are not much more representative than the smaller number of *Corticium* strains experimented with. All of the strains from soil direct and 11 of the strains from pine were taken at approximately the same time from the same nursery in Michigan by Mr. Glenn G. Hahn; despite the fact that these were the most recently isolated of the strains used, nearly all of them proved weak in the inoculations. Of the 17 strains which proved the weakest (out of 35), all but 3 were from this Michigan nursery. The 18 strains from other sources (5 from California, 2 from Minnesota, 2 from Kansas, 1 from Wisconsin, 2 from an unknown locality, and 6 from Washington, D. C., representing two coniferous and three dicotyledonous host genera), as shown by solid circles in figure 13, for the most part were rather closely grouped within the more virulent portion of the range. The coefficient of variability in the survivals allowed by the 35 *Pythium debaryanum* strains is 39 ± 3.6 per cent, while for the smaller number of original strains of *Corticium vagum* in experiments 71 and 72 it is 63 ± 9.7 per cent. It is evident from figure 13 that if there had not been a disproportionately larger number of strains from the Michigan nursery the variability of the *P. debaryanum* strains would have been much less than 39 per cent. The number of strains was, of course, altogether insufficient for either fungus to represent adequately a population as immense as the total number of strains of either of these omnipresent species. The above data, however, contain the only available information of which the writer is aware on variation in the virulence of different strains of *P. debaryanum*.

The evidence as a whole, both from the results shown in figure 13 and the experience with 6 other strains which were not used in the experiments on which figure 13 was based, lead the writer to believe that most strains of *Pythium debaryanum* taken from lesions in plants are ordinarily likely to prove rather virulent parasites on pine seedlings. It further appears that the variation in virulence between the different strains of *P. debaryanum* on pine seedlings is less than the variation in strains of *Corticium vagum*.

PYTHIUM INOCULATIONS ON UNHEATED SOIL.

Inoculations with *Pythium debaryanum* were made in western Kansas on a fine sand containing little humus after treating the soil with acid followed by lime. Commercial sulphuric acid was applied at the rate of 14.8 c. c. per square foot of bed, followed two days later by 25.5 grams of air-slaked lime raked into the soil (0.16 liter of acid and 0.274 kg. of lime per square meter). The acid was diluted before applying with 256 volumes of water. The seeds were sown in drills, and inoculum was placed in the drills at the time of sowing. Each unit involved approximately 11 linear inches of drill, and all

received equal quantities of seed. Three strongly parasitic strains of *Pythium* were used, and a total of 12 units of jack pine and an equal number of western yellow pine was inoculated with 12 interspersed units of each species as controls. The mean results are as follows:

Pinus banksiana.—Inoculated plats: Emerged, 64.2 ± 4.9 ; died during the next 17 days, 25 per cent. Control plats: Emerged, 85.5 ± 3.6 ; died during the next 17 days, 13 per cent.

Pinus ponderosa.—Inoculated plats: Emerged, 34.6 ± 1.8 ; died during the next 9 days, 39 per cent. Control plats: Emerged, 45.4 ± 1.3 ; died during the next 9 days, 25 per cent.

The difference in emergence apparently due to the inoculation is for the first species three and one-half and for the second nearly five times its probable error. While, of course, 12-unit means are insufficient to allow the calculation of entirely reliable probable errors, they give some idea of the amount of variability of the results and the confidence which can be given them. It is impossible to give any such expression applying directly to the damping-off percentages and their differences, for the reason that averages for this item have been made in the writer's work not by averaging the percentages for the individual units but by totaling all the seedlings and the dead seedlings on the plats to be averaged and recalculating the percentage from these figures. This seems the only safe method, as otherwise units in which germination is low by accident or by the action of parasites will be given an influence on the resultant mean entirely disproportionate to the number of seedlings which they contain. Average values for damping-off obtained by this method and by the method of averaging the percentages of the individual plats or pots are often very different; it not uncommonly happens that the units in which germination is lower than the average also have especially high damping-off percentages, both phenomena being caused by an unusual activity of parasites. In such case to average the percentages themselves usually gives a higher damping-off figure than to total the seedlings for the different units and redetermine the percentage, and the latter practice is considered the better. In the present case the differences in the damping-off percentages obtained by the two methods are not great. The figures obtained by averaging the percentages of the ultimate units are as follows:

Pinus banksiana.—Inoculated, loss 30.9 ± 5.0 per cent; controls, loss 13.2 ± 2.8 per cent.

Pinus ponderosa.—Inoculated, loss 40.0 ± 5.1 per cent; controls, loss 24.1 ± 3.3 per cent.

The differences between the inoculated and control plats in damping-off percentage were for the first species a little over and for the second a little under three times their indicated probable errors.

The results in general make it appear that the *Pythium* was able to kill some pines both before and after their appearance above the soil surface on the soil treated with the acid and lime. The control in this experiment did not receive the nutrient substratum added with the *Pythium* inoculum, but an experiment run under the same conditions at nearly the same time, in which seven strains of hyphomycetes with the same substrata entirely failed to decrease survival, indicates that the rice substratum was not in itself the cause of the observed result. The rather weak action of the *Pythium* in these experiments stands out in sharp contrast to the results with *Corticium vagum* in the same experiments, practically all emergence being prevented by most of the *Corticium* strains used, some of which had proved less active than *Pythium* in tests on autoclaved soil.

In a soil in Nebraska, somewhat similar but with more humus, 5.5 c. c. (three-sixteenths fluid ounce) of sulphuric acid per square foot applied in solution at the time of sowing had been found greatly to decrease damping-off. In different parts of beds treated with acid from 10 to 17 days earlier, 96 plats, each 3 inches square, were laid out, and each plat was inoculated at the center. Interspersed with these were 96 plats set apart as controls. Emergence had already begun at the time of inoculation. Jack pine, red pine, and Corsican pine were the hosts, and three *Pythium* strains of known parasitism, growing in pieces of prune agar the size of peas, constituted the inoculum. The damping-off after emergence was less than 1 per cent higher for the inoculated plats than for the controls. Even such a light inoculation would probably have given some results in autoclaved soil, so the experiment indicates, as would be expected, that this acid-treated soil was less favorable for *Pythium debaryanum* than steamed soil.

On pots containing entirely untreated soil the following series of inoculations were made at the time of sowing the seed:

Inoculation at one point in each pot:

- Experiment 25. Jack and western yellow pine, 1 pot of each inoculated; survival 13 days after emergence slightly greater in both than in the six controls.
- Experiment 27. Jack pine, 73 pots, 27 controls; average emergence, 59 in inoculated pots and 56 in controls; damping-off, 39 per cent in inoculated pots and 37 per cent in controls.
- Experiment 29. Jack, Corsican, and western yellow pine, 112 plats inoculated just as emergence commenced instead of at seed sowing, as in other cases, and 112 controls alternating with them; damping-off was less in the inoculated plats than in the controls.
- Experiment 31. Jack pine, 8 pots inoculated, 8 controls; inoculated, emergence 33 per cent, damping-off 13 per cent, survival 198; controls, emergence 38 per cent, damping-off 26 per cent, survival 196.
- Experiment 58A. Jack pine, 5 pots inoculated, 5 controls; inoculated, emergence 59 per cent, damping-off 32 per cent, survival 40; controls, emergence 51 per cent, damping-off 12 per cent, survival 45.

Inoculations at two points in each pot:

Experiment 26A. Jack pine, 3 pots inoculated, 4 controls; inoculated, emergence 29 per cent, as compared with 39 per cent in the controls; subsequent damping-off the same in both.

Inoculations at four points in each pot:

Experiment 58B. Jack pine, 5 pots inoculated, 5 controls; inoculated, emergence 51 per cent, damping-off 10 per cent, survival 46; controls, emergence 43 per cent, damping-off 22 per cent, survival 34.

Experiment 59A. Jack pine, 5 pots inoculated, 5 controls; inoculated, emergence 55 per cent, damping-off 2 per cent, survival 54; controls, emergence 50 per cent, damping-off 8 per cent, survival 46.

Of these experiments, No. 29 was in the original fine sandy soil of a nursery in Nebraska in which *Pythium* is commonly found native and damping-off losses are usually heavy. Experiments 58A and 59 were conducted on soil from the same source which had been kept dry in the laboratory for five years; experiments 25, 27, 31, and 58A were on greenhouse mixtures of sand and soil. In experiments 31, 58A, 58B, and 59 parallel inoculations were made on autoclaved portions of the same soil, with definitely positive results in three of the four cases. In the heated soil the results were positive, not only because of smaller losses in the controls but because the losses in the inoculated pots were actually heavier in the sterilized soil than in that untreated.

Inoculations broadcast:

Experiment 31. Jack pine, 8 pots inoculated, 8 controls; inoculated, emergence 31 per cent, damping-off 39 per cent, survival 129; controls, emergence 38 per cent, damping-off 26 per cent, survival 196.

Experiment 59. Jack pine, 5 pots inoculated, 5 controls; inoculated, emergence 58 per cent, damping-off 22 per cent, survival 45; controls, emergence 44 per cent, damping-off 2 per cent, survival 43.

Even with these broadcast inoculations the results on untreated soil were too indefinite to allow the drawing of positive conclusions. In both experiments much heavier losses than these resulted from inoculations on steamed soil. It is evident that experiments on sterilized soil do not always show what can be expected on ordinary soil. The same thing is indicated by the results of Edgerton with tomato wilt (36).

CONCLUSIONS AS TO THE PARASITISM OF *PYTHIUM DEBARYANUM*.

Pythium debaryanum has been found in low-altitude nurseries in all the species of conifers from which a serious effort has been made to obtain it, and its parasitism has been indicated in autoclaved soil on all of the conifers on which inoculation has been attempted. Therefore, although the work reported has been limited to a relatively small number of hosts, it seems likely that it will be found able to cause damping-off in most of the species of the *Abietoideæ* which suffer seriously from the disease. Just how active as a parasite it is

under ordinary nursery conditions is yet to be proved. The results in inoculations on disinfected soil, together with the frequency with which the fungus has been isolated from seedlings in the nurseries, lead the writer to believe that it is an important cause of disease in the seed beds. Further experiments on unheated soil, however, are considered desirable.

RHEOSPORANGIUM APHANIDERMATUS.

CULTURAL STRAINS.

A culture of a parasite on radishes and sugar beets, described by Edson (39) under the above name, was obtained from him, and another strain, shown by Edson's records to be a subculture from the same original strain, was furnished by the department of plant pathology of the University of Wisconsin. In parallel cultures on solid media this fungus proved in many ways remarkably like *Pythium debaryanum*, reacting in practically the same way to the different media on which it was grown both in relative growth rate and in spore production. Mycelium, chlamydospores, oogones, antheridia, and oospores are not recognizably different from those of *Pythium debaryanum*. The oospores have seemed on the whole slightly larger and the mycelium a little more inclined to aerial growth than most of the *Pythium debaryanum* strains, but neither difference was sufficient to have diagnostic value. Swellings of the hyphæ occurred at points in contact with glass, just as with *Pythium debaryanum* (Pl. I, figs. 5 to 7).

In liquid cultures the Rheosporangium was readily distinguished from Pythium by the formation of the presporangia described by Edson. Autoclaved cylinders of turnip, 15 to 20 mm. long, cut with a 5-mm. cork borer, proved convenient bases for growth of both Rheosporangium and Pythium in water culture and quite as satisfactory as sterilized beet seedlings. Presporangia were also produced in autoclaved soil, and in a single lot of corn-meal agar they were formed abundantly in the agar in Petri dish cultures. In none of the writer's cultures, either with flies, sugar-beet seedlings, or turnip cylinders as nutrient bases, were mature escaped sporangia or swarm spores commonly produced.

The Rheosporangium was not obtained in any of the numerous cultures made from coniferous seedlings or from seed-bed soil.

INOCULATION EXPERIMENTS.

The Rheosporangium cultures above referred to, strain 229 furnished by Dr. Edson and strain 351 received from the University of Wisconsin, were tested on pine and red-beet seedlings, with parallel inoculations with *Pythium debaryanum*. The results appear in Table VI.

TABLE VI.—Results of parallel inoculation with *Rheosporangium aphanidermatus* and *Pythium debaryanum* on pine seedlings in autoclaved soil.

Experiment number, host, and inoculating fungus, ^a	Number of pots.	Results.		
		Emerged (per cent of seed).	Damping-off (per cent).	Survival (per cent of seed).
No. 30, <i>Pinus ponderosa</i> :		<i>Per pot.</i>	<i>Per pot.</i>	<i>Per pot.</i>
Rheosporangium, strain 229.....	5	23	3	22
Pythium, 2 strains.....	5	14	38	9
Controls.....	5	20	22	16
No. 31, <i>Pinus banksiana</i> :				
Rheosporangium, strain 229.....	5	45	13	40
Pythium, strain 225.....	10	12	44	7
Controls.....	25	43	5	41
No. 58, <i>Pinus banksiana</i> :		<i>Per 5-pot unit.</i>		<i>Per 5-pot unit.</i>
Rheosporangium, strain 229.....	5	46	2	45
Pythium, 8 strains.....	40	2.6	50	1.3
Controls.....	10	78	0	78
No. 59, <i>Pinus banksiana</i> :				
Rheosporangium, strain 229.....	5	46	11	41
Pythium, 8 strains.....	40	15	35	10
Controls.....	10	64	0	64
No. 61, <i>Pinus banksiana</i> :				
Rheosporangium, strain 351.....	20	16	36	10
Pythium, 2 strains.....	20	2	57	1
Controls.....	20	60	2	59
No. 61, <i>Pinus banksiana</i> and beets in same pots:				
Pines } Rheosporangium, strain 351.....	5	1	(b)	(b)
Beets }		70	88	8
No. 61, beets alone:				
Rheosporangium, strain 351.....	5	43	72	12
No. 62A, beets:				
Rheosporangium {strain 229.....	15	89	1	88
{strain 351.....	4	42	35	27
Pythium, 2 strains.....	20	12	83	2
Controls.....	11	86	0	86
No. 62A, beets:				
Rheosporangium {strain 229.....	5	50	20	40
{strain 351.....	5	c 77	78	c 6
Controls.....	5	c 77	1	c 76
No. 62A, beets and <i>Pinus banksiana</i> in same pots:				
Pines } Rheosporangium, strain 229.....	5	64	14	55
Beets }		42	22	33
Pines } Rheosporangium, strain 351.....	5	46	33	31
Beets }		27	78	6
Pines } Controls.....	5	81	0	81
Beets }		67	0	57
No. 62B, Jack pine: ^d				
Rheosporangium {strain 229.....	2	58	14	50
{strain 351.....	2	53	10	48
Pythium, strain 258.....	2	10	100	0
Controls.....	3	82	0	82
No. 66, Jack pine:				
Rheosporangium {strain 229.....	5	63	9	58
{strain 351.....	5	80	52	39
Pythium, 47 strains and substrains.....	235	43	33	29
Controls.....	25	75	14	64
No. 67, Jack pine:				
Rheosporangium {strain 229.....	5	107	0	107
{strain 351.....	5	88	6	83
Pythium, 47 strains and substrains.....	235	51	26	38
Controls.....	23	87	5	83
No. 68, Red pine:				
Rheosporangium {strain 229.....	5	105	0	105
{strain 351.....	5	124	0	124
Pythium, 47 strains and substrains.....	235	86	27	63
Controls.....	18	104	0	104

^a Location of the inoculum: In experiment 30, at one point at the edge of each pot; in experiment 31, over the entire pot; in all other experiments, over one-quarter the area of each pot.

^b The breakage of the one seedling not killed while sprouting prevented the determination of results.

^c Double seed density in these pots; emergence and survival figures halved to allow direct comparison with other units. This high seed density may explain in part the higher loss in strain 351 than in strain 229.

^d Experiment 62B was conducted at the same time as 62A, but with a different soil.

Table VI shows that in experiments 30 and 67 the loss was less in the *Rheosporangium* pots than in the controls and that in experiment 68 the results were entirely negative, while in the remaining seven

experiments the losses were heavier in the Rheosporangium pots. Especially in experiments 61 and 62A the evidence indicates very strongly that both germination loss and subsequent damping-off of the seedlings which come up can be caused by inoculation with Rheosporangium on jack pine under favorable inoculation conditions. It is, however, obvious that in all of the experiments the parallel inoculations with *Pythium debaryanum* gave much more positive results. The Pythium was active under conditions in which the Rheosporangium gave no evidence whatever of parasitic capacity. It furthermore appears that the two strains of Rheosporangium, though probably identical originally, differed in virulence at the time of their comparison in these experiments. The greater virulence of strain 351 was quite distinct in most of the comparative tests on beets as well as on pines. The possibility that the original culture was really a composite of two or more strains, of which different ones survived in the subcultures kept at Washington and Madison, respectively, seems worth considering. Such an accident might also have been responsible for the divergence of Pythium strains 131 and 295 referred to in another section.

Further evidence of the parasitism of Rheosporangium was obtained in inoculations with cultures reisolated from seedlings killed by the original strains in experiment 62. Typical Rheosporangium, identified by presporangium formation, was easily recovered from the damped-off seedlings in pots of pines only, those of beets only, and the pots in which both hosts were sown. The recovery of a virulent Pythium strain from a single one of the pots inoculated with the weaker Rheosporangium shows that despite the absence of disease in the controls a slight amount of contamination did occur. However, the comparative ease with which the Rheosporangium was isolated from seedlings in other pots inoculated with it and the fact that it has never been obtained in the numerous cultures made from controls and from pots inoculated with other organisms leave little room for doubt that the strains isolated were really recoveries of the Rheosporangium used in the original inoculations. The results of reinoculation with these strains are shown in Table VII.

From Table VII and by comparison with Table VI it appears—

(1) That in one experiment each on jack pine and red pine the reisolated Rheosporangium strains gave positive results. In a second experiment on jack pine (No. 67) the difference between the Rheosporangium pots and the controls was not significant.

(2) That, as in Table VI, the Pythium strains used proved on the whole decidedly more parasitic than the Rheosporangium strains. In experiment 66 this is not shown by the percentage of seedlings damped-off, but is sufficiently evident when the germination loss as well as the subsequent damping-off percentage is considered, the survival being here, as in most other cases in which

either of the groups of pots compared is seriously affected by parasites, the most convenient index of the comparative activity of the fungi used. In such a comparison as that between the *Rheosporangium* pots and the controls in experiment 68 (Table VII), accidental variations in emergence, of course, overshadow the slight effect of the fungus, and the definitely determinable percentage of loss after emergence is the only value which can serve as a basis for any definite conclusion.

TABLE VII.—*Results of inoculations on pine seedlings with initial and reisolated strains of Rheosporangium aphanidermatus compared with parallel inoculations with Pythium debaryanum.*

Experiment number, host, and inoculating fungus.	Reisolation source.	Number of pots.	Number of strains.	Results.		
				Emerged (per 5-pot unit).	Damp- ing-off (per cent).	Survival (per 5-pot unit).
No. 66, <i>Pinus banksiana</i> :						
Rheosporangium—						
Strain 229.....	Edson from beet.....	5	1	63	9	58
Strain 351.....	do.....	5	1	80	52	39
Strains 403 and 404.....	Strain 229 from beet.....	10	2	78	43	44
Strains 405, 406, and 407.....	Strain 351 from beet.....	15	3	63	43	36
Strains 417, 430, and 433.....	Strain 351 from pine.....	15	3	72	42	41
Average.....		50	10	70±2.7	40	42±3.8
Controls.....		25		75	15	64
Pythium, average.....		235	47	43	33	29
No. 67, <i>Pinus banksiana</i> :						
Rheosporangium—						
Strain 229.....	Edson from beet.....	5	1	107	0	107
Strain 351.....	do.....	5	1	88	6	83
Strains 403 and 404.....	Strain 229 from beet.....	10	2	91	8	84
Strains 405, 406, and 407.....	Strain 351 from beet.....	15	3	92	4	88
Strains 417, 430, and 433.....	Strain 351 from pine.....	15	3	83	3	80
Average.....		50	10	90±2.4	4	86±2.9
Controls.....		23		87	5	83
Pythium, average.....		235	47	51	26	38
No. 68, <i>Pinus resinosa</i> :						
Rheosporangium—						
Strain 229.....	Edson from beet.....	5	1	105	0	105
Strain 351.....	do.....	5	1	124	0	124
Strains 403 and 404.....	Strain 229 from beet.....	10	2	102	1	101
Strains 405, 406, and 407.....	Strain 351 from beet.....	15	3	105	5	100
Strains 417, 430, and 433.....	Strain 351 from pine.....	15	3	100	3	97
Average.....		50	10	105±2.3	2	102±2.5
Controls.....		18		104	0	104
Pythium, average.....		235	47	86	27	63

A frequency graph based on the survivals of the 50 individual pots inoculated with *Rheosporangium* in experiment 68 yields a rather interesting asymmetrical curve (fig. 17). The shape of the curve is taken as indicating that in a large number of the pots the inoculation produced no effect, while in the smaller number of pots in which the inoculation apparently "took," the loss was rather heavy. This is a rather common phenomenon in inoculations which are only partly successful, part of the pots being free or practically free from loss, while others are nearly cleaned out. It will be seen again in

figure 18. This suggests, further, that part of the lack of activity was due to the failure of the fungus to maintain itself vigorously in the soil till the pines reached a stage of sprouting in which they could be readily attacked. Direct inoculations after the seed starts to sprout are therefore desirable to supplement the experiments reported. The survivals in the controls did not show any such asymmetrical distribution.

While the *Rheosporangium* has given rather definite evidence of parasitism on *Pinus banksiana* under favorable conditions, the activity of the strains available has been much less than that of the *Pythium debaryanum* strains. In view of the fact that the fungus has not so far been isolated from pine it can be concluded to have no general importance in pine seed beds. Its very rapid growth on prune agar makes it very easy to isolate when present.

PHYTOPHTHORA SPP.

Phytophthora fagi

R. Hartig has been commonly reported as the cause of death of seedlings of various plants in Europe, including conifers and herbaceous plants as well as beech (5, 8, 15, 55, 56, 57, 59, 73, 104.) It has been grouped

with the rather indefinite *Phytophthora omnivora* and with *P. cactorum*, the enemy of cactus, ginseng, and other plants. Wilson (147, p. 54) considered it distinct, but Rosenbaum (114), in his biometric comparison of *Phytophthora cactorum* and a single strain of *P. fagi*, failed to find significant morphological differences. If *P. fagi* is even physiologically different from the American strains of *P. cactorum*, its introduction into the United States is to be guarded against. There is certainly no fungus in the United States causing the damage to coniferous seedlings which European reports have attributed to *P. fagi* there. As *P. fagi* attacks roots, it presumably can be carried in soil as well as on plant parts.

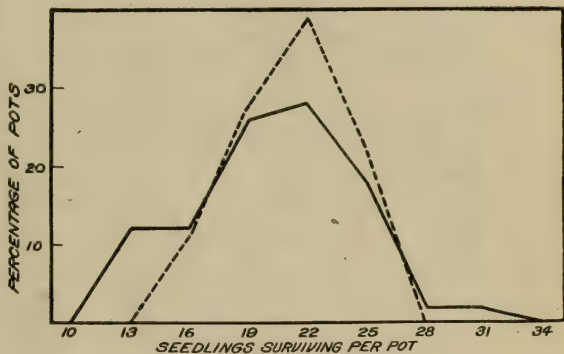


FIG. 17.—Diagram showing the results of inoculation of *Pinus resinosa* seedlings with *Rheosporangium aphanidermatus*, as indicated by the number of seedlings surviving in inoculated pots (solid line) and control pots (broken line). The shape of the curve for the inoculated pots is taken as indicating that a large proportion of them were entirely unaffected by inoculation, while those which were at all affected suffered considerably. This is a frequent result in inoculations with weak parasites added at the time of sowing the seed.

A test made on jack pine with a culture of *Phytophthora cactorum*, furnished by the department of plant pathology of Cornell University, resulted negatively. At the time of sowing the seed three pots were inoculated with cultures on nutrient agar inserted at several points in each pot. After emergence additional fragments of prune-agar cultures were placed in contact with the seedlings, and they were

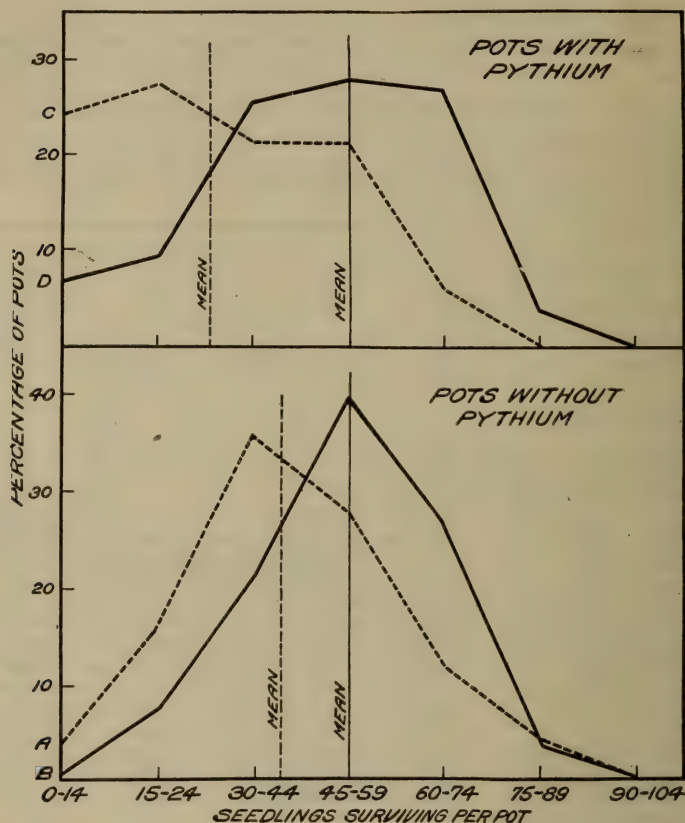


FIG. 18.—Frequency of pots with different numbers of surviving seedlings of *Pinus banksiana*, inoculation experiment No. 31. The solid lines represent pots to which cultures of saprophytic organisms were added. The broken lines are based on pots to which no saprophytes had been added. The solid lines are based on 78 pots in the upper graph and 80 pots in the lower one; the broken lines on 33 pots in the upper and 25 pots in the lower graph. *Pythium debaryanum* was added just after sowing the seed at a single point in each pot represented by the two upper lines. Cultures of saprophytes were applied broadcast two days before the *Pythium* inoculations were made.

sprayed with a spore suspension. The pots were covered with glass to increase atmospheric moisture, and the seedlings were occasionally sprayed with an atomizer. The soil was an autoclaved mixture in which simultaneous inoculations in a different room with *Pythium* and *Corticium* proved successful. The failure of the *Phytophthora* may possibly have been due to the lower temperature at which the pots inoculated with it were kept (15° to 20° C.).

A species of *Phytophthora* was isolated by Mr. R. G. Pierce from damped-off *Pinus resinosa* in Minnesota and used in four inoculation experiments, the results of which appear in Table VIII. In the first of these experiments unboiled water was used on the pots, and mice obtained access to the pots of the second test. Probably as a result of these things infection occurred in the controls in both cases, and the results were inconclusive; in the later experiments these two sources of infection were eliminated, and in experiments 68 and 72B the controls were free from disease. Parasitic activity was indicated rather strongly in experiments 68 and 72 (on *P. resinosa* and *P. banksiana*) and to a certain extent in experiment 66. In experiment 67 it was evident that the *Phytophthora* was nearly or entirely inactive. Comparison of the results in experiments 66 and 68 with the results from inoculations with *Rheosporangium aphanidermatus* in the same experiments (Table VII) suggests that the *Phytophthora* may be better able to attack the pine from which it was isolated than the *Rheosporangium*, while the latter fungus caused considerably more destruction to *Pinus banksiana* than the *Phytophthora*. Comparison of the results in the pots inoculated with *Phytophthora* and those inoculated with *Pythium debaryanum* in all the experiments indicates that the *Phytophthora* strains used were less virulent than most of the strains of *P. debaryanum* and very certainly less destructive than the most active strains of either *P. debaryanum* or *Corticium vagum*. This species of *Phytophthora* has been reisolated from damped-off *Pinus ponderosa* in experiment 72.

Direct inoculations of the stems of seedlings of *Pinus resinosa* soon after they emerge from the soil have so far confirmed the lack of parasitism of *Phytophthora cactorum* and of the cultures of *Phytophthora* sp. grown by the writer. The identity of this species has not yet been determined. It is able to grow only about one-fourth as rapidly as *Pythium debaryanum* on the medium which has been used for isolation and may therefore be more common in the seed beds than the small number of isolations by the planted-plate method would indicate. However, its oospores, larger and darker than those of *Pythium debaryanum* (usually over 20 μ in diameter), should have been recognized in the routine microscopic examination of planted-plate cultures had this species been frequently present, even if it had not grown fast enough to get out ahead of the other organism and allow isolation. It is not believed that it is common enough in pine seed beds to be of importance, even if other strains should be found more virulent than those which have been available.

MISCELLANEOUS PHYCOMYCETES.

A fungus, apparently referable to the somewhat indefinite *Pythium artotrogus* (Mont.) De Bary, was isolated by Mr. Glenn G. Hahn from *Pinus resinosa* in Michigan and from damped-off *Pinus bank-*

siana in pots of autoclaved soil which had received tap water at Washington, D. C. It agreed both in the appearance and measurements of its spiny oogones and smooth oospores with *Pythium artotrogus* (*P. hydnosporus*) as described and figured by Butler (23). In addition to the spores which Butler describes, there appeared in apparently pure prune-agar cultures of different strains bodies with smooth walls, of somewhat irregular ovoid outline, and mostly larger than either oospores or oogones. They are very much less abundant than the sexual spore forms. Their greatest diameter varied from 11 μ to over 40 μ . The germination of these bodies was not observed. Efforts to induce the fungus to produce swarm spores by growing them in liquid nutrient media and transferring them to pure water were unsuccessful. This failure to produce zoospores is further indication of the identity of the fungus with that described by Butler, who says that asexual reproduction is unknown.

The strain from Michigan was a rather weak growing organism, difficult to maintain in tube cultures without rather frequent transfers. Its parasitic activity in the experiments reported in Table VIII is nil or negligible. Because of the poor seed and small number of seedlings involved in experiment 72B, the percentage of damping-off there given means only a single seedling dead. The Washington strains, on the other hand, though evidently not strong parasites, did apparently cause the death of a number of seedlings. The best evidence of this is in experiment 68, in which there was damping-off in each of the five 5-pot units containing the Washington strains and none in any of the 18 control pots. The available strains were less active not only than *Pythium debaryanum*, but less than the *Rheosporangium* and *Phytophthora* strains used. The fungus is believed to be a potential parasite on pine seedlings, but not one of any general importance. What is probably the same fungus had appeared in the writer's cultures from western nurseries in conjunction with *P. debaryanum*, but not commonly, and it had not been isolated. While its growth rate is only about half that of *P. debaryanum* on prune agar, it is nevertheless so much faster than that of many fungi that it should have been more often obtained in culture were it at all common in damped-off seedlings.

Another fungus, presumably an oomycete but producing only chlamydospores in the writer's cultures, was obtained from damped-off olive seedlings furnished by Prof. W. T. Horne and from soil direct, both at Berkeley, Calif. The fungus is apparently the same as one which has been occasionally seen in cultures from pine seedlings in the Middle West, but had not before been isolated. The hyphæ are ordinarily nonseptate, and the growth on corn-meal agar is superficially much like that of *Pythium debaryanum*, but with greater tendency toward local zonation and aerial growth and less

than half as rapid. Chlamydospores are mostly intercalary, at first subspherical, soon becoming polygonal, and after a few days they shrivel and exhibit thick, angular walls. In size the unshrunk spores usually lie between 8 and 12 μ in diameter, but bodies as large as 20 μ occasionally occur. Antheridia have not been observed, and the shriveled bodies are not believed to be oospores, though the observations made have not been sufficient to exclude such a possibility. No other spore form was obtained in water culture, using various nutrient substrata. In inoculation the strain from olive (the "undetermined Phycomycete" included in Table VIII) has given negative or nearly negative results in three inoculation tests in which other fungi gave positive results. In a test not included in the table, in which *Pinus ponderosa* was the trial host, damping-off was slightly higher in the inoculated pots than in the controls, but the difference was apparently due to accidental infection with Botrytis and *Pythium debaryanum*. As all the seedlings in pots inoculated with *P. debaryanum* in this additional experiment were killed, the relative unimportance of this strain of the small-spored fungus was further indicated. An additional test of both the olive strain and the strain from soil was made by inoculating seedlings of *Pinus banksiana* and *P. ponderosa* growing on filter paper in Petri dishes. Some of these were kept wet with water, some with an inorganic culture solution, and some with the inorganic solution plus peptone and dextrose. Agar cultures were applied directly to the seedlings. The seedlings inoculated with the small-spored fungus remained alive as long as the control seedlings, while parallel inoculations with *Pythium debaryanum* resulted in the early decay of the seedlings.

TABLE VIII.—Results of inoculations with miscellaneous oomycetes on pines in autoclaved soil at the time of sowing.

[In all the experiments included in this table, the inoculum consisted of fragments of agar cultures distributed with the seed at one side of each pot over about one-fourth of the pot area. The controls received sterile agar in the same way.]

Experiment number, host, and inoculating fungus.	Number of pots.	Results.		
		Emerged.	Damp- ing-off.	Survival.
No. 66, <i>Pinus banksiana</i> :		<i>Per 5-pot unit.</i>	<i>Percent.</i>	<i>Per 5-pot unit.</i>
Phytophthora sp.—				
Strain 358.....	5	70	30	49
Strain 372.....	5	75	28	54
Strain 375.....	5	94	16	79
Pythium artotrogus (?), Michigan strain.....	4	115	14	99
Undetermined Phycomycete.....	5	83	9	76
Controls.....	25	75	14	64
No. 67, <i>Pinus banksiana</i> :				
Phytophthora sp.—				
Strain 358.....	5	96	1	95
Strain 372.....	5	88	3	85
Strain 375.....	5	99	0	99
Pythium artotrogus (?), Michigan strain.....	5	102	2	100
Undetermined Phycomycete.....	5	98	0	98
Controls.....	23	87	5	83

TABLE VIII.—Results of inoculations with miscellaneous oomycetes on pines in autoclaved soil at the time of sowing—Continued.

Experiment number, host, and inoculating fungus.	Number of pots.	Results.		
		Emerged.	Damping-off.	Survival.
No. 68, <i>Pinus resinosa</i> :		<i>Per 5-pot unit.</i>	<i>Percent.</i>	<i>Per 5-pot unit.</i>
Phytophthora sp.—				
Strain 358.....	5	104	7	97
Strain 372.....	5	109	18	89
Strain 375.....	5	98	5	93
<i>Pythium artotrogus</i> (?), Michigan strain.....	5	121	0	121
<i>Pythium artotrogus</i> (?), Washington, D. C.—				
Strain 821.....	5	122	1	121
Strain 823.....	5	120	9	109
Strain 831.....	5	96	5	91
Strain 832.....	5	110	6	103
Strain 833.....	5	94	1	93
Undetermined Phycomycete.....	5	84	2	82
Controls.....	18	104	0	104
No. 72A, <i>Pinus resinosa</i> :		<i>Per 3-pot unit.</i>		<i>Per 3-pot unit.</i>
Phytophthora sp.—				
Strain 372.....	3	20	35	13
<i>Pythium artotrogus</i> (?), Michigan strain.....	3	62	0	62
<i>Pythium artotrogus</i> (?), Washington, D. C.—				
Strain 821.....	2	45	7	42
Strain 831.....	3	37	0	37
Strain 833.....	3	40	25	30
Controls.....	16	35	5	33
No. 72B, <i>Pinus ponderosa</i> :				
Phytophthora sp.....	3	8	50	4
<i>Pythium artotrogus</i> (?), Michigan strain.....	3	13	8	12
<i>Pythium artotrogus</i> (?), Washington, D. C.—				
Strain 821.....	3	11	0	11
Strain 831.....	2	29	6	27
Strain 833.....	2	6	0	6
Controls.....	14	9	0	9

OTHER FUNGI.

Data on the possible relation between various other fungi and the damping-off of conifers have been already summarized by Hartley, Merrill, and Rhoads (68, p. 546-550). *Pestalozzia funerea* on the basis of the experiments of Spaulding (135), *Botrytis cinerea* on the basis of observation and very preliminary inoculations, and *Trichoderma koningi* on cultural evidence only are all believed to be potential causes of damping-off, though not ordinarily important. *Alternaria* sp. is under a certain amount of suspicion on account of its frequent association with the damping-off of conifers, but it has never been used in experiments. *Rhizopus nigricans* (incorrectly reported as *Mucor*), *Trichothecium roseum*, *Rosellinia* sp. from nursery soil, *Chaetomium* sp. from maple roots, strains of *Penicillium* and *Aspergillus*, *Phoma betae*, and *Phoma* spp. are all reported to have been used in inoculations with negative results.

Since the publication of the above summary a preliminary successful inoculation experiment with *Botrytis cinerea* on recently emerged *Pseudotsuga taxifolia* has been found briefly mentioned in an article by Tubeuf (140) on another disease. Further experiments with va-

rious strains of *Botrytis*, both from conifers and from other hosts (the latter supplied by the departments of plant pathology of the California and New York (Cornell) Agricultural Experiment Stations), have already yielded confirmatory evidence of the parasitism of *B. cinerea*.

While a considerable number of fungi have been considered in the foregoing, it is entirely possible that there are still parasites which have received no consideration and that some of them may perhaps be important. The moist-chamber method of culturing parasites for isolation yields only those which produce spores readily; the planted-plate method is not well adapted to the isolation of slow-growing fungi or bacteria. It is suggested that in further culture work with damped-off conifers an attempt be made to secure slow-growing organisms by dilution plates of teased-up fragments of recent lesions.

RELATIVE IMPORTANCE OF THE DAMPING-OFF FUNGI ON CONIFERS.

The relative importance of the different damping-off parasites is something that has not been thoroughly investigated for any host. The most information on this point is that given by Busse, Peters, and Ulrich (22) for sugar beet. In this case they find the specialized *Phoma betae* distinctly the most important, with *Pythium debaryanum* second and *Aphanomyces levis* third.

Peters (100) apparently considered *Rhizoctonia* unimportant as a cause of beet damping-off. The opposite was indicated by a small number of cultures by Edson (38) from beet seedlings on Kansas and Colorado soil. These yielded more *Corticium vagum* than any other parasite and no *Pythium* at all. Johnson (81) states that most of the damping-off of tobacco seedlings is due to *Pythium debaryanum* and *Corticium vagum*. Atkinson (1), speaking for cotton in Alabama, and Sherbakoff (127, p. xcv; 128; 129), speaking for truck crops in Florida, make *Corticium vagum* the important damping-off parasite, with *P. debaryanum* negligible. Horne (oral communication) found the same situation in tobacco seed beds in Cuba. Atkinson (3), in an article on trees, held that many of the cases of damping-off attributed to *P. debaryanum* are in reality due to *C. vagum*. Peltier (98, pp. 336-337) has reported *Rhizoctonia solani* as the cause of damping-off of a large number of plants, recording his observation of the damping-off of seedlings of nearly 50 species of miscellaneous genera and cuttings of 13 different species, all of which he attributes to the *Rhizoctonia*. He does not state whether in this case he used diagnostic methods likely to detect *Pythium debaryanum* if it had been present.

For the conifers, no very reliable data on relative importance have been published. Numerous European reports emphasize the damage due to *Fusarium* spp., while a smaller number attribute loss to *Phytophthora fagi* or to both. There seems to have been little effort to determine the presence or absence of *Corticium* or *Pythium*, so these reports can not be given great weight. Spaulding's evident belief (136) in the importance of *Fusarium* has more weight, as he was on the lookout for the other fungi; the moist-chamber diagnostic method employed in most of this work was, however, not well adapted to the detection of either one. The same is true of the work of Rathbun (106), in which dilution plates of seed-bed soil were employed. Rankin (105) attributes to *Fusarium* spp. the greatest importance in tree seed beds in this country, with *Pythium debaryanum* and *Rhizoctonia* spp. important in certain cases. Gifford (46) emphasizes the importance of *Fusarium*, while Clinton (28) apparently found *Rhizoctonia* (*Corticium vagum*) especially prevalent in the examinations he made.

On the basis of the data presented or summarized in this bulletin, it is believed that of the various organisms which have been connected with damping-off in coniferous seed beds *Pythium debaryanum*, *Corticium vagum*, and *Fusarium* spp. include all of importance. The others, either because of low indicated virulence or infrequent occurrence, and in most cases both, do not seem to merit extensive consideration.

In order to form an idea of the relative frequency of the parasites named above as important, there have been brought together in Table IX the results of the examination of 438 damping-off foci in untreated beds and 304 foci which have appeared in beds which had received various disinfectant treatments. The data are presented by foci rather than by individual seedlings, as was done in the census reported by Busse and his coworkers. Most of the diagnoses were made by planting recently diseased seedlings in plates of solidified prune agar, all the seedlings taken from the same focus, or "patch," of damped-off seedlings being put into the same Petri dish. The resulting growth was in some cases transferred to a tube for later examination, but was usually examined directly in the plate. In a smaller number of foci the seedlings were macerated and examined directly without recourse to culture methods. As *Pythium debaryanum* does not commonly fruit in diseased seedlings of pine or of tobacco (81) and its hyphæ are both difficult to find and not in themselves considered a sufficient diagnostic character, this latter method of examination is not so satisfactory for the determination of *Pythium* as it is for *Corticium*, which is easily recognized by its

thick-walled truncate-tipped hyphæ and characteristic branching. A further difficulty in the direct-examination method, unless the seedlings are sectioned, is in distinguishing between *Corticium* hyphæ which are in the tissues and those outside. The well-known habit of the *Corticium* of sending hyphæ superficially over the surface of plants which it is not appreciably injuring makes it evident that only hyphæ actually found in the tissues have diagnostic value. Direct microscopic examination is, furthermore, very likely to fail to detect *Fusarium*. The planted-plate method therefore appears the better of the two, and the results of the culture diagnoses appearing in the lowest two lines of Table IX deserve probably more attention than the total occurring a few lines above, in which the results of direct examination of the seedlings are also included. The high proportion of *Corticium* reported from the Michigan and Minnesota nurseries is probably due in part to the fact that most of the examinations made there were of the direct microscopic type.

TABLE IX.—Results of the examination of damping-off foci in coniferous seed beds for *Pythium debaryanum*, *Corticium vagum*, and *Fusarium* spp.

Grouping.	Untreated beds.				Beds of heated soil.			Beds treated with strong acids.				
	Foci examined.	Number showing—			Foci examined.	Number showing—			Foci examined.	Number showing—		
		Pythium.	Corticium.	Fusarium.		Pythium.	Corticium.	Fusarium.		Pythium.	Corticium.	Fusarium.
By locality:												
Berkeley, Calif.	4	3	1	2	.....	.....	.....	.....	5	5	0	2
Manitou, Colo.	22	0	19	0	.....	.....	.....	.....	.....	.....	.....	.....
Monument, Colo.	34	6	20	13	.....	.....	.....	.....	.....	.....	.....	.....
Garden City, Kans.—												
Garden City Nurseries	18	4	0	9	14	5	0	7	28	8	2	9
Kansas Nurseries (sand)	20	4	9	7	15	2	0	6	16	9	2	8
Halsey, Nebr.	224	124	45	155	28	10	0	17	99	34	2	61
Cass Lake, Minn.	42	15	21	5	.....	.....	.....	.....	1	0	0	0
Dundee, Ill.	4	0	4	1	.....	.....	.....	.....	.....	.....	.....	.....
East Tawas, Mich.—												
Beal Nurseries (sand)	45	14	33	2	.....	.....	.....	.....	1	1	0	0
East Tawas Nurseries	13	11	7	1	.....	.....	.....	.....	13	7	6	2
Washington greenhouse	12	3	3	9	7	2	0	3	.....	.....	.....	.....
Total:												
Number	438	184	162	204	64	19	0	33	163	64	12	82
Percentage	100	42	37	47	100	30	0	52	100	39	5	50
By diagnostic methods:												
Direct examination—												
Number	156	39	108	25	0	.....	.....	.....	16	6	8	4
Percentage	100	25	69	16	.....	.....	.....	.....	100	38	50	25
Planted-plate cultures—												
Number	282	145	54	179	64	19	0	33	147	58	4	78
Percentage	100	51	19	63	100	30	0	52	100	39	3	53

TABLE IX.—Results of the examination of damping-off foci in coniferous seed beds for *Pythium debaryanum*, *Corticium vagum*, and *Fusarium* spp.—Con.

Grouping.	Beds treated with formaldehyde.			Beds treated with copper sulphate.			Beds treated with zinc chlorid.			All treated beds.						
	Foci examined.	Number showing—		Foci examined.	Number showing—		Foci examined.	Number showing—		Foci examined.	Number showing—					
		Pythium.	Corticium.		Fusarium.	Pythium.		Corticium.	Fusarium.		Pythium.	Corticium.	Fusarium.	Pythium.	Corticium.	Fusarium.
By locality:																
Berkeley, Calif.													5	5	0	2
Manitou, Colo.																
Monument, Colo.																
Garden City, Kans.—																
Garden City Nurseries...	6	0	6	3	1	0	0	1	3	1	0	3	52	14	8	23
Kansas Nurseries (sand)													31	11	2	14
Halsey, Nebr.	34	20	1	24	6	3	0	5	8	0	0	5	175	67	3	112
Cass Lake, Minn.													1	0	0	0
Dundee, Ill.																
East Tawas, Mich.—																
Beal Nurseries (sand) ..										1	1	0	0	0	0	0
East Tawas Nurseries...	8	5	4	0	6	5	3	3	5	3	0	2	32	20	13	7
Washington greenhouse													7	2	0	3
Total:																
Number	48	25	11	27	13	8	3	9	16	4	0	10	304	120	26	161
Percentage	100	52	23	56	100	62	23	69	100	25	0	63	100	39	9	53
By diagnostic methods:																
Direct examination—																
Number	8	5	4	0	5	4	2	2	5	3	0	2	34	18	14	8
Percentage	100	63	50	0	100	80	40	40	100	60	0	40	100	53	41	24
Planted-plate cultures—																
Number	40	20	7	27	8	4	1	7	11	1	0	8	270	102	12	153
Percentage	100	50	18	68	100	50	13	88	100	9	0	73	100	38	4	57

The data on the different nurseries do not allow any generalizing on the basis of locality except to say that all of the fungi seem quite generally distributed in the Lake States and Great Plains region. In general, it appears that the *Fusaria* as a group are more common than either of the other fungi; as they grow more slowly than either the *Pythium* or the *Corticium*, they were probably rather more common relatively than even the plate-culture method indicated. It also appears that the *Pythium* occurred in more foci than the *Corticium* in the beds examined. Further culture work, perhaps by the method of dilution plates of fragments of lesions, seems desirable, especially in the East and the Northwest, regions in which there are large coniferous nurseries and in which nothing like a parasite census has been attempted. Observations on the type of focus occurring in most of the nurseries in the Rocky Mountains leads the writer to believe that *Corticium* will be found especially important there.

While the data on the fungi in foci in disinfected beds are insufficient to serve as a basis for much in the way of conclusions for any individual treatment, they in general agree with the assumption, which knowledge of the fungi would favor, that *Corticium* is the

most easily controlled by soil disinfection (see the bottom line in the last four columns of Table IX). Its poor adaptation for aerial dissemination would lead one to expect to find it seldom in beds treated with efficient disinfectants. The entire absence of *Corticium* in heated soil therefore seems somewhat significant. The rather high *Corticium* yield in the formaldehyde plats is of some interest in view of the reported inefficiency of formaldehyde in destroying *Corticium vagum* on potato tubers (48, 50). As will be noted from the data given, more than one suspected parasite was often found in what appeared to be a single focus. This was probably in some cases due to independent foci being nearly concentric; it also in some cases undoubtedly means that one of the organisms found was only secondary. In the beet-seedling cultures by Busse and his associates, individual seedlings yielded two or more potential parasites in 100 of their nearly 1,300 examinations. It not infrequently happened in the work on pine seedlings that no fungus recognized as a likely parasite could be isolated. This was especially true in plate cultures when *Rhizopus* or *Trichoderma* happened to be abundant, as both are very fast growing and often suppress parasites. This is an additional reason for the development of some method as a dilution plate of lesion fragments for diagnosing damping-off.

Even an accurate and complete census of the organisms present in the different foci could not be directly interpreted in terms of relative importance. None of the parasites so far used in inoculation have been vigorously parasitic under all conditions. Of both *Corticium vagum* and *Pythium debaryanum* some strains, microscopically indistinguishable from the others, are very weak as parasites. Only part of the *Fusarium* species are parasitic on pine, and data showing which are and which are not parasitic are known for only a very few. There is therefore no fungus which can be said positively to be the cause of any particular damping-off "patch" simply because it was found in some of the dead seedlings in the patch. In an occasional exceptional case, such as the large *Corticium* patch in figures 7 and 8, there is such a vigorous growth of the fungus that its predominance is undoubted, but such cases are rather rare. A census throws light on the importance of the different fungi, but can be interpreted only in the light of inoculation results.

For *Pythium* and *Corticium* the inoculation data do not permit any simple comparison between the two, for the reason that neither is uniform. Each has strains of high virulence and strains having practically no effect on pines. In the inoculations in autoclaved soil at sowing time the strongest strains of *Corticium vagum* have on the whole caused more damage than any of the *Pythium* strains, but, on the other hand, there has seemed to be a higher proportion of very

weak strains of *C. vagum* than in the case of *Pythium*. In inoculations on *Pinus banksiana* and *P. ponderosa* in Kansas sand treated with acid followed by lime, the average *Corticium* was very much more destructive than even the strongest *Pythium* strains, allowing practically no germination in most cases. On the other hand, in experiments in which the inoculum was applied directly to *Pinus resinosa* and *P. ponderosa* seedlings, either immediately after germination or after the older parts had become resistant, the *Pythium* has been the more effective. The inoculation evidence so far available justifies so nearly equal emphasis on the two that it can practically be eliminated from the calculations. It is the writer's opinion that the *Corticium* strains are probably rather less virulent on the average than the *Pythium* strains, but perhaps better able to maintain themselves and spread from one seedling to another in most soils. The evidence of Table IX that the *Corticium* seemed less frequent in the damping-off foci is more or less counterbalanced by the apparent larger size of many of the disease patches which it seems to cause in the seed beds. Nearly all the large clean areas such as are shown in figures 7 and 8 have been found to contain abundant *Corticium* hyphæ. The evidence on the whole seems to indicate a very nearly equal importance for the two fungi. The *Pythium* is probably somewhat the more important for the stations at which most of the cultures in Table IX were made, but the *Corticium* has received more emphasis from other observers in this country and is indicated by the writer's observations to be more important in the western mountains than any other damping-off fungus.

The inoculation evidence for *Fusarium* spp., though less complete than for *Corticium* and *Pythium*, is nevertheless rather helpful in indicating their importance rating. None of those so far tested in inoculations at sowing have shown the destructiveness of the average strains of *Pythium* or of the stronger strains of *Corticium*; while this is only in part a test of virulence and in part a test of the ability of the fungus to grow saprophytically in the soils used, the indication is that no one *Fusarium* species is the equal in destructive capacity of either *Corticium vagum* or *Pythium debaryanum*. However, when all of the *Fusarium* species which occur in the seed beds are considered, the group as a whole may prove quite as important or even more important than either of the other two fungi. The data already at hand rather definitely indicate considerable importance for all three.

DAMPING-OFF FUNGI AS CAUSES OF ROOT-ROT AND LATE DAMPING-OFF.

As has been already stated, root-rot, often with frequent recovery, has been commonly observed in seedlings several weeks old. It has been especially common in the vicinity of old damping-off foci in

which *Corticium vagum* appeared to be the active parasite, but beyond this indication of the causal relation of *C. vagum* it was not known which of the damping-off fungi were able to attack the roots of seedlings too old to be killed by damping-off. To throw light on this point, seedlings of *Pinus ponderosa* and *P. resinosa* grown in autoclaved soil in the greenhouse and approximately $1\frac{1}{2}$ months old were inoculated with different fungi. There had been a certain degree of early damping-off in these pots, but it had apparently ceased before the inoculations were made. The inoculum used consisted of cultures on rice introduced through the drainage holes at the bottoms of the pots. The strains of *Pythium debaryanum* and *Corticium vagum* used were the ones which had given maximum results in earlier inoculation experiments at the time of sowing. The strain of *Fusarium ventricosum* was the only one available, and the *Fusarium moniliforme* strains were all of approximately equal virulence, the three used having given as much evidence of parasitism as any of the strains of this species in the earlier damping-off experiments. Three pots of each pine were inoculated with each strain. Two 3-pot units of each pine were set aside as controls and inoculated with sterile rice. In addition, three pots of each pine were kept in the same bench without the addition of any inoculum, for comparison with the controls with rice. The results of this experiment, taken a month after the inoculations were made, with the seedlings averaging $2\frac{1}{2}$ months old, appear in Table X. The roots of the living seedlings were washed out carefully with water to permit examination.

The results in so far as they indicate root-rot of the oldest seedlings are best shown by the figures in columns 4 and 5. These seedlings were so far advanced that the fungi had not been able to kill them, and nearly all would probably have recovered if they had not been dug up. It will be noted from column 4 of Table X that a considerable portion of the *Pinus ponderosa* seedlings with root-rot had already made their recovery apparent by pushing out adventitious roots above the decayed portion at the time they were examined.

For *Fusarium ventricosum* there was only the merest indication of ability to attack pine roots at this stage. For *F. moniliforme* the evidence is somewhat better, more pots being included and the difference in healthy-topped seedlings with injured roots between the inoculated pots and the controls being approximately twice its indicated probable error for each species. The percentage of root-injured seedlings in the *Pythium debaryanum* pots exceeded that in the controls in each species by between three and four times the probable error of the difference, while the difference in percentage between the *Corticium vagum* pots and the controls is approximately four times its probable error in the case of *Pinus ponderosa* and five and one-half times its probable error in the *Pinus resinosa* pots. The

weak point in the results is, of course, the insufficiency of the 6-pot and 9-pot groups as bases for probable-error determination. The indicated relative ability of these different fungi to cause root-rot is about the same as their relative ability to cause the damping-off of sprouting seed and young seedlings, as indicated by the results of the earlier experiments in which inoculations were made at the time of sowing. The fact that only the very strongest available strains were used and that the pots were rather heavily inoculated is to be kept in mind in considering these results. As in the seedlings examined in the nursery beds, when a root system was partly rotted it was only the younger portions of the roots that were affected. The evidence obtained from this experiment needs to be amplified by experiments with other coniferous hosts, other strains of the fungi, and under other conditions. The experiment just described furnishes the only evidence available on the relation of the important fungi *Pythium debaryanum* and *Corticium vagum* to the root-rot of conifers and is therefore presented as a preliminary contribution.

TABLE X.—Results of root inoculations of older pine seedlings with damping-off fungi.

Host and inoculating fungus.	Number of—		Seedlings which developed root-rot (per cent).				
	Pots.	Seed- lings.	Tops still healthy.			Killed.	Total.
			Root recovery.		Average of in- dividual pots.		
			Started.	Not started.			
1	2	3	4	5	6	7	8

Pinus ponderosa:							
Pythium debaryanum, strains 295, 550, and 810. <i>a</i>	9	71	27	25	53±4.5	4	56
Corticium vagum, strains 147, 213, and 747. <i>a</i>	9	56	16	34	51±3.5	4	54
Fusarium moniliforme, strains 249, 251, and 260. <i>b</i>	9	64	19	27	42±6.2	0	45
Fusarium ventricosum.....	3	18	17	39	50	0	56
Controls.....	6	41	2	15	22±6.5	0	17
Controls without rice.....	3	18	0	17	23	0	17
Pinus resinosa:							
Pythium debaryanum.....	9	140	3	16	18±4.0	12	31
Corticium vagum.....	9	146	3	16	21±2.4	13	33
Fusarium moniliforme.....	8	128	0	11	12±3.7	2	13
Fusarium ventricosum.....	3	39	0	5	4	0	5
Controls.....	6	115	0	3	4±2.0	6	10
Controls without rice.....	3	51	0	0	0	2	2

^a For relative virulence of these strains on younger seedlings as compared with other strains of the same species, note their position in figures 11 and 14.

^b For performance of these strains in inoculations at time of sowing, see an earlier publication (68, table 2).

The figures in column 7 give information as to the percentage of late damping-off resulting from the inoculations. A certain percentage of the early type of damping-off appeared in some of the

pots, as there were still present a number of soft-stemmed seedlings from seeds which were slow in germinating. These younger seedlings were excluded in counting the dead, the rule being to include only plants which had developed a sufficiently rigid stem to remain upright after death. Comparison of the percentage of killed with the total percentage attacked for the two pines is rather interesting. As has already been pointed out, while *Pinus resinosa* suffers very heavy damping-off losses at a number of nurseries it seems to be less susceptible than some other species to parasitic injury during the sprouting period, before the seedlings appear above the soil surface. Observation of beds of this species during different seasons has indicated that it has not a greater susceptibility, but rather the fact that its susceptibility lasts longer, which causes it to suffer as seriously as it does at certain nurseries. It is indicated in Table X that the succulent root tips of *Pinus ponderosa* are just as easily attacked by damping-off parasites as those of *P. resinosa*—in fact, considerably more easily attacked, as indicated by the figures in column 8. With the *P. ponderosa* seedlings, however, the older parts of the roots had become resistant at this age in nearly all cases, while of the affected *P. resinosa* seedlings more than one-third were still unable to limit the lesions, and death resulted.

In general, this experiment indicates that *Corticium vagum* and *Pythium debaryanum* are able to cause the death of some pine seedlings which have developed rigid stems and that both are also able, as has been found by other workers in the case of sugar beets, to cause "root sickness," the rot of the younger portions of the root systems, in seedlings which have developed too much resistance to be killed. The evidence for the parasitism of the two *Fusarium* species on these older root systems is not so good; as in the experiments on younger seedlings, their ability to attack the pines is probably less than that of the other two fungi. Further inoculation experiments are desirable both with these fungi and with others on the roots of seedlings too old to succumb to the more ordinary types of damping-off.

RELATION OF ENVIRONMENTAL FACTORS TO DAMPING-OFF.

In the earlier section dealing with disease control, mention was made of the general belief on the part of men who have had experience with seedling diseases that damping-off is favored by thick seeding, by much organic matter, especially by poorly rotted manure in the soil, and by excessive moisture in the air and soil. It is also commonly stated that high temperature favors the disease; on this point there is perhaps a less general agreement. Practically all the evidence on these points is observational.

DENSITY OF SOWING.

The relation between the disease and thick sowing was strikingly indicated for tobacco seedlings in a single experiment by Johnson (82). For pines the only available information is from four experiments on *Pinus banksiana*. The results of the first two appear in figure 19. In both experiments there is an indication of an increase in the percentage of diseased plants as the seed density is increased. There is, however, no such marked relation as in Johnson's work. As the pines were sown in drills, they were so close together even in the less dense plats that no very great increase in the ease of spread

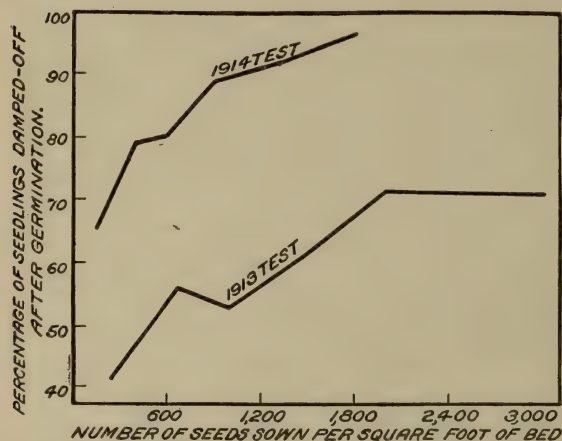


FIG. 19.—Diagram showing the extent of damping-off in drill-sown *Pinus banksiana* in plats with different seed densities. The regular seed density at this nursery was 600 seeds per square foot.

of the disease was to be expected from increasing the density. Greater differences should be expected in broadcast beds. That heavier losses have been found in drill-sown beds than in those sown broadcast (69, 139) is presumably explained by the fact that with equal numbers of seed per square foot of seed bed the seedlings are much closer together in drills

than in broadcast beds, and thus the spread of the mycelium of parasites from one seedling to another is facilitated.

Two tests of different seed densities were also made in 3-inch pots of autoclaved soil in the greenhouse. Each regular pot was sown with 28 seeds (equivalent to 600 per square foot). The pots were inoculated by adding to each a single small fragment of an agar culture of *Pythium debaryanum*. Uninoculated pots showed an emergence of approximately 50 per cent of the seed and were entirely free from subsequent damping-off in both experiments. The results appear in Table XI.

In this case not only the damping-off after emergence but the loss before the seedlings appeared bore an apparent relation to sowing density. In the field experiments there was no evidence that the loss before the seedlings appeared was affected by seed density.

TABLE XI.—Results of inoculation, at the time of sowing, with *Pythium debaryanum* on *Pinus banksiana* in different sowing densities in pots of autoclaved soil.

[The percentages of "Damping-off," columns 4 and 7, are based on the number of seedlings; the percentages given in columns 3, 5, 6, and 8 are based on the number of seeds.]

Density of seed sowing.	Number of pots in experiment.	Results (per cent).					
		Experiment 58.			Experiment 59.		
		Emerged.	Damp-ing-off.	Sur-vival.	Emerged.	Damp-ing-off.	Sur-vival.
1	2	3	4	5	6	7	8
Regular.....	10	15	43	10	26	13	23
Double.....	5	8	65	3	8	91	1
Triple.....	5	1	100	0	11	34	7
Regular, but 10 additional seeds near point of inoculation.....	5	6	33	4	17	37	11

MOISTURE AND TEMPERATURE FACTORS.

The relation of damping-off to moisture and temperature are subjects less easily studied. In 1907 and 1908 Mr. W. H. Mast, then supervisor of the Nebraska National Forest, conducted daily counts of the number of seedlings damped-off and compared these records with temperature and rainfall records. The writer in 1909 repeated his work, maintaining parallel records of damping-off, air and soil temperatures, soil moisture, atmospheric humidity, wind movements, and evaporation. The 1909 records of damping-off, temperature, soil moisture, and evaporation appear in figure 20. The damped-off seedlings were counted and removed in the morning and evening, the day period thus being in most cases 10 to 11 hours and the night period 13 to 14 hours. Because the period was not always the same length, the data are reduced to a per hour basis. Air temperature was recorded by a sheltered thermograph 3 feet above the soil surface. The evaporation graph represents the mean loss per hour from two porous cup atometers of the writer's own design, in which the rather long and slender Chamberlain filter bougie was used and supported in a horizontal position just above the soil surface so as to be under as nearly as possible the same atmospheric conditions as the seedlings. The two bougies were placed at right angles to each other in order to eliminate as far as possible the effect of change of wind direction on their mean loss. While the rain-correction mounting had not at that time come into use, the error due to rain absorption appeared negligible; atometers filled shortly before rainfall were read immediately after without any gain being found in the water in the reservoir. The psychograph and wind-movement records are not presented, as the evaporation values are more easily interpreted. Soil moisture was periodically determined in the soil of the

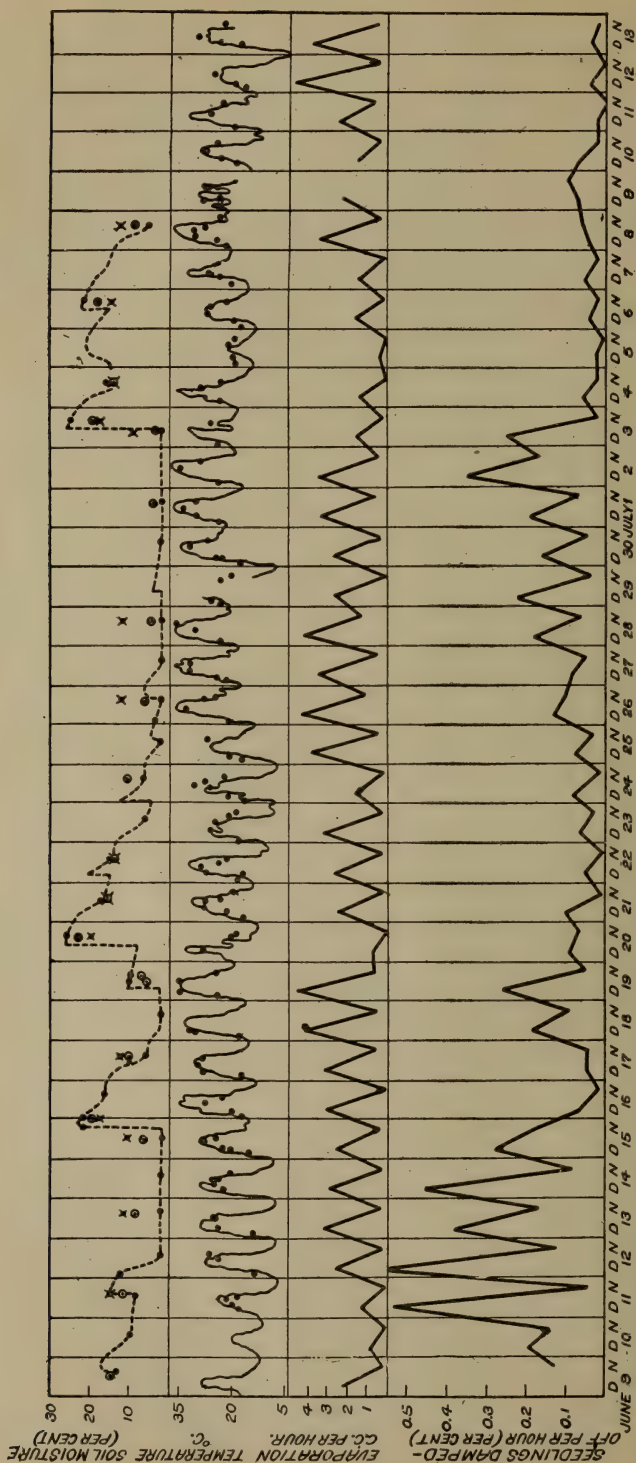


FIG. 20.—Diagram showing the progress of damping-off in beds of *Pinus banksiana* at a nursery in Nebraska and indicating the moisture and temperature conditions. The evaporation from porous-cup atmometers was measured and the dead seedlings counted, night and morning. As the day (D) and night (N) periods into which the time was thus divided were not of equal length, these figures are converted into an hourly basis. The temperature curve is taken from a sheltered thermograph 1 meter above the surface of the beds, while the dots accompanying this curve indicate readings of a thermometer whose bulb was buried 3 cm. below the soil surface. For the temperature and soil-moisture records, the vertical lines indicate 6.00 a. m. Explanation of symbols referring to soil moisture: ● = At depth of 0 to 0.6 cm., ○ = At depth of 0.6 to 2.5 cm., × = At depth of 2.5 to 5 cm.

plats on which the seedling counts were conducted, each determination representing two, and in some cases four, points. The determinations for the upper one-fourth inch of soil, made more frequently than for lower levels, are connected in figure 20 by a dotted line, which gives some idea of the amount of moisture in the surface soil during the periods between determinations. The determinations were too infrequent to permit anything more than an estimate of the moisture conditions between determinations, but the writer, having before him the records of the times and amounts of rainfall and artificial watering as well as the evaporation and soil-moisture determinations, is in a better position to make such an estimate than the reader. The dotted line which gives this estimate should not be depended on to show what the percentage of moisture was at any one time, but is believed reasonably reliable as showing whether in general the soil was wet or dry. In interpreting the soil-moisture records, it should be kept in mind that the soil was very sandy, the wilting coefficient of composite samples from various parts of the nursery, as determined by the indirect method of Briggs and Shantz in the Laboratory of Biophysical Investigations of the Bureau of Plant Industry, being only 3.4 per cent. The hygroscopic moisture in dry air for the soil of the plats actually under consideration was indicated by repeated determinations for the surface soil on dry days to be in the neighborhood of or slightly below 2 per cent. The nursery is located in a region of large temperature fluctuations, where the air during the day is generally dry, and consequently the dew is heavy at night.

The first result of interest is the difference between the damping-off for the day and the night periods. In the records of every day but two, more seedlings went down during the day period than during the night, the differences in most cases being large. As the evaporation and temperature showed similar day and night fluctuations, it is difficult to say whether temperature or moisture conditions were responsible. The other interesting result brought out by the graphs is the sudden drop in the general level of the damping-off graph following the rains of June 15, June 19-20, and July 3. In each of these three cases the damping-off came up again only after the soil moisture came down.

The fact that in the daily fluctuations the damping-off varied directly with the evaporation rather than inversely is an apparent contradiction of the generally accepted doctrine that moisture favors the disease. This contradiction is, however, only apparent. During the first part of the damping-off period, when the seedlings are still soft, the recognition of damping-off depends on the decay of that part of the stem just above the soil surface which allows the seedling to fall over. This usually takes place at this nursery as

a result of the extension upward of lesions which have started on the parts a little below the soil surface. It is supposed that such decay takes place most rapidly at high temperatures and that it is the temperature rather than the evaporation graph which the damping-off is following in these early day and night fluctuations. During the latter part of the damping-off period a dying seedling shows its first signs of distress in the drying up of its leaves, the stem being too stiff to go down until after the infection has gone far enough in the roots to cut off most of the water supply. It is, of course, under dry conditions that such a sign of distress will be most in evidence. During the latter part of the damping-off period it is therefore altogether likely that the day and night fluctuations are caused, at least in part, by the higher evaporation rate which obtains during the day. This is a relation not to the rate of progress of the disease, but rather *to the rate at which the symptoms of disease appear in plants already seriously affected.*

The drop in damping-off following the increased soil moisture of June 15, 19-20, and July 3 also apparently contradicts established doctrine. While it is ordinarily true that a wet soil is a cold soil and that in the rainy weather which causes wet soil the evaporation is usually low, it does not seem possible on inspection of the graphs for these items to attribute entirely the reduction of damping-off during these periods of wet soil either to low temperature or to low evaporating power of the air. Lowered soil temperature probably had something to do with the reduced loss following the rains. It is also suggested that a sudden change in moisture content may temporarily hinder a soil fungus by decreasing its air supply. In this sandy soil the fungi can work at very considerable depths during dry periods. Initial lesions have been found as much as 12 inches below the surface. If this soil is as completely changed in its aeration qualities by wetting as the sandy soil with which Buckingham (19) worked, a rain might result in a rather sudden change in the level at which the fungus is able to operate.

On the whole, the graphs tend to confirm the common statement that high temperature favors damping-off. It must, however, be borne in mind that in uncontrolled field plats several factors vary simultaneously, and it is impossible to definitely attribute any observed phenomenon to any one of them. Furthermore, it is not possible to say for the seedlings at different ages just how long it will take a factor to exert an effect on the damping-off curve. An additional consideration is that a method of investigation which gives entirely reliable information on the speed with which the disease develops does not necessarily throw light on the conditions under which the greatest total amount of disease can be expected before the seedlings become old enough to resist attack. High temperatures,

within reasonable limits, are expected to increase the speed with which the disease works, but these should also hasten the development of the host to a point at which infections are unable to cause death. It is the total amount of damage in the beds rather than the damage per unit of time which is of practical importance. For a number of reasons, then, the method followed in obtaining the data for these graphs can not give information of maximum value. While data of the sort mentioned are of undoubted interest and would be of still more value if the records had been commenced when the first seedlings appeared instead of a few days later, the relation of any specific factor to the total extent of the disease can be better determined by comparing plats in series in which the factors are as far as possible controlled and varied one at a time. To vary soil moisture and soil temperature independently will prove somewhat difficult, but it can be done with the proper facilities. Some work with environmental factors should be done under conditions of artificial inoculation in the greenhouse, in which the different damping-off parasites can be experimented with separately, as it is obvious that the factors which favor the activity of one may not be favorable for another.

CHEMICAL FACTORS.

Chemical factors are presumably also important, as the soil is in most cases the culture medium for both the parasite and the host. The much greater activity of *Pythium debaryanum* in autoclaved soil than in untreated soil may be due to the larger quantity of soluble organic matter commonly present in autoclaved soil. *Pythium debaryanum* has been found more sensitive to unfavorable substrata in artificial culture than *Corticium vagum* and is apparently more dependent on soil organic matter in the nurseries than is *C. vagum*. For example, in the normal humus-containing surface sand in the beds at Cass Lake, Minn., both *Pythium* and *Corticium* occurred frequently in the damped-off seedlings, while in beds a few feet distant, from which enough of the surface soil had been removed to leave no humus, nearly all the damping-off foci contained abundant *Corticium*, and no *Pythium* could be found. With both fungi and, in addition, with two species of *Fusarium* (68) heavy inoculation has been more successful in experiments at the time of sowing than light inoculation. This has been thought possibly due in part to the larger amount of nutrient substratum added in the heavy inoculations, allowing better saprophytic development of the fungus in the soil. In each of the two experiments with *Pythium* reported in Table XI, a 5-pot unit was treated with corn-meal infusion and another with prune infusion at the time of inoculation. In both experiments germination was lower, damping-off after germination higher, and the survival less than half as great in the pots with

infusion as in the inoculated pots not so treated. In the first experiment 5-pot units of unheated soil were also inoculated in the same way. In these also both the units which received infusions showed less germination and more loss after germination than the unit which received no infusion, though the differences were smaller than in the autoclaved soil. In the second experiment the light inoculation used failed to cause material loss in the unheated soil units, even though two of them were treated with the infusion as in the previous test and two others received triple portions of the infusion.

The experience in the nurseries, in which heavy applications of manure, and especially poorly rotted manure, in a number of cases have apparently resulted in increased disease, and the finding of Fred (43) that green manures recently plowed under favored the work of *Corticium* have already been mentioned. The addition of dried blood at two nurseries in Kansas was in both cases followed by very much heavier loss than in the controlled plats. The only instances known to the writer in which the addition of organic matter to the soil has shown any indication of materially decreasing damping-off (with the exception, of course, of the organic disinfectants) are the result reported by Gifford (46) with tankage, a single case in the writer's experience with bone meal, and the cases in which cane sugar has seemed to decrease losses somewhat (67). It is of some interest to note that the experience available also indicates increased disease as a result of the addition of inorganic nitrogenous substances. Sodium nitrate and sodium nitrite have both given some indication of increasing damping-off. Ammonium sulphate in six separate series has in every case resulted in decreased stands, though unfortunately in experiments in which the damped-off seedlings were not counted. Ammonium hydroxid, though apparently having some initial value as a disinfectant, as indicated by early damping-off losses, in a number of cases has been followed by very heavy total losses. This experience is of some interest in view of the apparently rather general belief that plants on a soil rich in nitrogen are especially susceptible to disease.

The chemical factor for which there is perhaps the most evidence of a relation to damping-off of conifers is acidity. The fact that sulphuric-acid soil treatment has been found to be one of the most effective means of controlling the disease, that its value is mainly lost if lime is later added to the soil, that soil treatment with sulphur in a number of cases has seemed to decrease the disease, and that lime alone and wood ashes have had either no effect or have apparently increased the damping-off whenever they have been tried, all suggest that soil acidity is not favorable to the disease. Additional indication of this appears in figure 12. The acidity determinations serving as the basis for the graph were made by Dr. L. J. Gillespie,

of the Bureau of Plant Industry. The estimates of the relative seriousness of damping-off are very approximate, based in part on observation only. The stations at which damping-off is rated as 1 are places at which it has been reported by nurserymen or foresters as negligible or absent. The estimates for stations 10, 11, 14, and 15 are based entirely on the reports of others, and for station 5 on the basis of counts of damped-off seedlings made by Mr. R. G. Pierce and Mr. Glenn G. Hahn. The writer personally has made the estimates or checked the estimates of the nurserymen at the other stations. A considerable degree of correlation between the hydrogen-ion exponent and the amount of damping-off appears on the face of the graphs, the coefficient being 0.75 ± 0.07 . If the correlation is calculated with the H^+ concentration itself instead of its negative exponent, the coefficient, in this case itself negative, is not so high (-0.58 ± 0.11). All of the above data on acidity relation have been picked up incidentally in connection with other work and are merely suggestive. The suggestion, however, seems sufficiently strong to warrant further experimental work directed specifically at the relation between soil acidity and the disease.

The indication in the graph that damping-off is not serious in soils in which the hydrogen-ion exponent (P_H)⁶ is less than 6 is of particular interest, in view of the experience of Hawkins and Harvey (71) with cultures of *Pythium debaryanum* on potato juice. They obtained good growth through a range of acidity from P_H 3.4 to 5.8, with no growth or practically none at 3.06 or 8.4. If this represents the acid tolerance of the fungus in the soil solution, it is evident that ordinarily acid soils can not be expected to remain free from damping-off because of inhibition of this particular fungus. This suggests that the apparently salutary influence of soil acidity in decreasing the damping-off of some of the conifers may be exerted in the direction of increasing the resistance of the host rather than of inhibiting the parasites. In any case, it must be kept in mind that as the numerous conifer hosts commonly grown in nurseries have many different habitat preferences and many very different parasites of potential importance, it is not to be expected that there will be found any such constant relation between any factor and the amount of disease as would be expected in a disease in which only a single parasite and a single host are involved.

⁶ P_H 6 is equivalent to a hydrogen-ion concentration, expressed in mols per liter, of 1×10^{-6} or 0.000001. The higher the exponent, the smaller the hydrogen-ion concentration. An exponent of 7 means approximate neutrality. In dealing with this exponential form of expression, it should be kept in mind that P_H 6 means ten times and P_H 5 one hundred times the hydrogen-ion concentration indicated by P_H 7. Conversely, the concentration of hydroxyl-ions at P_H 7 is one hundred times as great as at P_H 5.

BIOLOGIC FACTORS.

Mention has already been made of two strictly biologic factors which may influence the amount of damping-off. Taylor (138) and Rathbun (106) have found *Fusarium* not only at considerable depths in the soil of pine seed beds, but viable *Fusarium* spores without hyphæ in the alimentary canals of earthworms and insect larvæ in the soil, and they attribute to the migrations of these and to the tunnels which various animal forms make in the soil a possible importance in the distribution of damping-off *Fusaria*. A likely relation between *Corticium vagum* epidemics in pine seed beds and the character of the weed flora has also been considered (66).

The relation between the damping-off parasites and other microorganisms in the soil is also a matter of some interest. The effect of the microfauna of the soil on the microflora in general has been considered by Russell and others in a number of papers. The effect of soil disinfection by heat in favoring the work of artificially introduced soil-inhabiting fungous parasites, apparently a rather frequent phenomenon and quite evident in the inoculation experiments with *Pythium debaryanum* reported in the present bulletin, has been in other cases attributed to the removal of bacteria and other fungi which might compete with the parasites (36, 80). Heating soil is known to produce physical changes and also very considerable chemical changes both in organic and inorganic substances. These must not be ignored in considering the effect of previous soil heating on parasite activity. With a view to determining whether all the difference noted in the behavior of *P. debaryanum* in heated soil is due to the direct effects of the heating or in part to the elimination of competing microorganisms, an experiment was conducted in 3-inch pots of autoclaved soil in which 111 of them were inoculated with agar cultures of the *Pythium* at one point in each pot shortly after seed sowing. The seeds sown in each pot approximated 136, considerably more than are used on equal areas of nursery seed bed. Of these, fifteen 5-pot units and one 3-pot unit had been inoculated broadcast with rice or nutrient agar cultures of various organisms supposed to be saprophytic on pines. These included *Phoma betae*, *Phoma* sp., *Chaetomium* sp. (from a maple root), *Rhizopus nigricans*, *Trichothecium roseum*, *Trichoderma koningi*, *Aspergillus* spp. (including one with black and one with bright-colored spore heads), *Rosellinia* sp. (from soil), *Penicillium* sp., an undetermined bacterium, and three undetermined higher fungi. The whole 78 pots inoculated with *P. debaryanum* and saprophytes, the percentages being based on the total number of seeds in the case of emergence and survival and on the number of seedlings which appeared above ground for damping-off loss, as compared with those which had received the parasite only, gave results as follows:

Pots with saprophytes: Emergence, 47.4 ± 0.86 per cent; damping-off, 9.1 per cent; survival, 41.0 ± 1.23 per cent.

Pots without saprophytes: Emergence, 35.7 per cent; damping-off, 14.3 per cent; survival, 29.2 per cent.

It has been noted in the attempts to diagnose damping-off by planted-plate cultures that when *Rhizopus* appears *Pythium debaryanum* is not frequently obtained. It is therefore of some interest to note that in this case, in the two 5-pot units which received *Rhizopus* in addition, the parasite killed only 1.2 per cent and 3.3 per cent, respectively, of the seedlings which appeared above the soil.

At the same time pots not inoculated with parasites were sown, 16 other 5-pot units were inoculated with the same saprophytes as those used in the *Pythium* inoculated pots, while 25 pots were left entirely without inoculation. A certain amount of damping-off occurred in these pots also as a result of accidental infection. The results were as follows:

Pots with saprophytes: Emergence, 47.8 ± 0.8 per cent; damping-off, 3.9 per cent; survival, 43.7 ± 0.95 per cent.

Pots without saprophytes: Emergence, 43.0 per cent; damping-off, 5.2 per cent; survival, 38.4 per cent.

It is of some interest to note that in these pots also the 5-pot units inoculated with *Rhizopus* suffered less from damping-off than the average of the saprophyte-inoculated pots.

The probable-error values given above are based on the variability of the emergence and survival figures of the different 5-pot units. No individual figures are available to serve as a basis for the determination of the variability of the pots without saprophytes. The 16 units which support the error determinations are, of course, not a sufficient number to give an entirely reliable index of variability, though these 16 units are respectively derived from the combination of a total of 78 and 80 ultimate units. The distribution of the data appears to be such as to justify the use of probability methods. Of the 64 items which went into the germination and survival calculations, 34 showed a deviation equal to E_s (probable error of a single unit), 9 to a deviation equal to $2E_s$, and only one a deviation equal to $3E_s$.

All of the above figures are based on the results at the end of 10 days after average emergence in the pots. The pots were kept on the benches till practically all damping-off had ceased, 36 days after emergence. As additional accidental infection with saprophytes certainly, and probably with parasites, occurred during this period, the results at the end of the tenth day are considered to give a better indication of the effect of the original inoculations. It is of some interest, however, to note that during the period from the tenth to the thirty-sixth day the difference between the pots to which sapro-

phytes had been added and those which received no saprophytes showed a slight increase, proportionally as well as in the absolute figures. At the end of the 36 days the survivals on all the pots were counted separately. The average number of seedlings per pot were as follows:

Without Pythium:

Without saprophytes, 42.8 ± 2.3 ; with saprophytes, 52.1 ± 1.1

With Pythium:

Without saprophytes, 30.1 ± 2.4 ; with saprophytes, 48.1 ± 1.4 .

The difference in the survivals in favor of the pots with saprophytes in the first case is 9.3 ± 2.5 , three and two-thirds times its probable error. In the second case it is 18.0 ± 2.8 , more than six times its probable error.

In general, it appears that in this experiment the inoculation of sterilized soil with saprophytes gave the seedlings some protection both against damping-off due to accidental infection with unidentified parasites and from the additional loss caused by light inoculation with *Pythium debaryanum*. The indication is, as would be expected, that only part of the favoring influence of heat sterilization of soil on introduced *P. debaryanum* is immediately due to the elimination of competition with other fungi. If a mixture of different bacteria and fungi had been added to each of the pots instead of but one or two organisms to each 5-pot unit, the effect might have been more marked.

It will be noted that for all the groups (fig. 18), whether with or without Pythium inoculation and with or without added parasites, the frequency polygon is asymmetrical, indicating by its shape, as did the frequency polygon of survivals in pots inoculated with *Rheosporangium* (fig. 17), that with infections which do not kill all of the seedlings the selection tends to be by pots rather than by seedlings. In other words, in pots in which the parasites succeed in killing any of the seedlings, they usually kill a considerable number. The tendency is illustrated not only by inspection of the graphs, but by the variability of the different groups. The greater variability in survivals between different pots was in both cases in the groups in which both the damping-off after emergence and the survival percentages indicated the largest loss. The percentages of seedlings damped-off during the entire 36 days following emergence and the coefficients of variability of the survivals of the individual pots at the end of that time are as follows:

Without Pythium:

Without saprophytes, 15.5 per cent damped-off; coefficient of variability, 39 ± 4.2 per cent.

With saprophytes, 11.1 per cent damped-off; coefficient of variability, 28 ± 1.6 per cent.

With *Pythium*:

Without saprophytes, 27.5 per cent damped-off; coefficient of variability, 67 ± 7.8 per cent.

With saprophytes, 16.9 per cent damped-off; coefficient of variability, 39 ± 2.4 per cent.

This tendency has been frequently observed in experiments in which inoculum is applied to the soil at the time of sowing. Even in experiments in which a relatively small proportion of the seedlings are killed, some of the pots are nearly or entirely cleaned out. It is taken as an indication that failure of inoculation to give results is often due to the inability of the fungus to maintain itself in a vigorous condition till the germinating seed is far enough along to allow easy infection. It may also be in part due to lack of uniformity of the soil in different pots affecting virulence of parasites or resistance of hosts.

In addition to this experiment on autoclaved soil, a somewhat similar experiment was conducted in a nursery in the Kansas sand hills on soil which had been treated with sulphuric acid, followed by lime raked into the soil. Saprophytes, for the most part the same strains that had been used in the experiment in the greenhouse, were added to 24 plats, each of one-half square foot, of *Pinus banksiana* and 24 of *P. ponderosa*, with 16 interspersed plats of each species serving as controls. The saprophytes were growing on rice, part of which was added to the plat with the inoculum in addition to the fungous mycelium. Damping-off was rather heavy in this soil from accidental infection or from parasites which survived the initial acid treatment, no parasites having been artificially introduced. The loss was probably due to *Corticium vagum* or *Fusarium* spp. rather than to *Pythium debaryanum* in this case. In both pines, emergence was slightly better in the control plats than in those to which the saprophytes had been added, the difference for *Pinus banksiana* being less than half its probable error and for *P. ponderosa* slightly more than its probable error. Damping-off for the first few days after emergence was somewhat less in the controls in one species, but higher in the saprophyte-inoculated pots in the other. The saprophytes therefore gave no evidence of effective competition with the parasites on this acid-lime treated sand.

While the competition for water which seems to be the form of competition most common among green vascular plants is not likely to be of significance between fungi such as those which cause damping-off, a very little observation of the growth of mixed cultures of the parasites and other organisms in Petri dishes is sufficient to make one realize that the latter may very considerably decrease the activity of certain of the parasites. In nutrient agar most of the fungi and bacteria introduced from the soil in attempting parasite isolations,

as well as to a less extent the paramécia, nematodes, and amœbæ which develop in such plates, exert a very considerable limiting influence on the growth of most of the damping-off fungi. That they should also limit the growth of parasites in soil, whether by the production of toxic compounds, the exhaustion of food materials, or in other ways, seems entirely reasonable. The results in the writer's experiments on heated soil warrant the suggestion that further trials should be made of the introduction of vigorously growing bacteria or molds, preferably mixed cultures containing a number of different organisms, on seed beds which have been disinfected by some such method as steam or hot water, which leaves the soil in a favorable condition for the development of accidentally reintroduced parasites. If such treatment should be successful in improving the rather disappointing results with soil heating at some nurseries, it might easily become of practical value, as the cultivation of certain of the more easily grown saprophytes on a scale large enough to yield considerable quantities of bacterial or spore suspensions should be fairly easy and entirely practicable in an operation as intensive as that of raising coniferous seedlings.

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SUMMARY.

(1) Damping-off in nurseries is caused mainly by seedling parasites which are not specialized as to host; *Pythium debaryanum* and *Corticium vagum* are probably the most important of these. Damping-off of various herbaceous hosts, including ferns, is often caused by specialized parasites which are limited to a particular host or group of hosts. *Phoma betae* is a rather extreme example of such specialization. For the conifers all the damping-off appears to be due to parasites of the generalized type.

(2) Damping-off of trees, as of herbaceous plants (with the exception of the cases caused by specialized seed-carried parasites), is ordinarily serious only in seed beds or cutting beds in which large numbers of plants are crowded together in a small space. In most of the forest nurseries it is a much more serious matter in conifers than in dicotyledonous seedlings.

(3) The most serious losses in conifers are ordinarily from the root-rot type of damping-off, occurring soon after the seedlings appear above ground and while the hypocotyls are still soft. Losses due to the killing of dormant or sprouting seed by parasites before the seedlings appear above the soil are also frequently serious, sometimes necessarily more so than the later types, as in extreme cases more than half of the seed or young seedlings are destroyed in this way. Damping-off due to infections of parts above the soil surface is serious only under extremely moist atmospheric conditions. The late type of damping-off, in which the roots are rotted after the stem becomes too rigid to be easily decayed, is ordinarily less important than the early types. Seedlings more than 2 months old are ordinarily able to recover from infections by the damping-off fungi. Even after the first month, seedlings with part of their root system killed often recover.

(4) It is possible that damping-off has a certain value as a selective agent by eliminating weak individuals in the seed-bed stage and allowing only the best trees to go into forest plantations. This value, however, is believed to be slight. Disinfectant treatments of seed beds, even when controlling early parasitic losses very well, allow a considerable percentage of disease during the last part of the damping-off period, often as much as occurs at the same stage of development in untreated beds. As it is only this late damping-off in which differences in individual resistance of the seedlings seem to be of importance in determining whether or not they succumb, it is believed that whatever selective value the disease may have will appear in a larger proportion of the damping-off in the treated than in the untreated beds.

(5) Of the different conifers, reports are available as to the susceptibility of 63 species. Species which are especially susceptible at some nurseries may prove more resistant than the average at others. *Pinus resinosa*, which is especially subject to loss at some nurseries, is believed to be so because its growth at these nurseries is slow and its period of susceptibility is therefore especially long. In its early stages it does not seem especially susceptible. Representatives of all the commonly grown genera of the Abietoideæ have been reported by one observer or another as decidedly susceptible. The reports on junipers and other members of the Cupressoideæ, on the other hand, have indicated a considerable amount of group resistance to damping-off.

(6) The best control method appears to be the disinfectant treatment of the seed-bed soil before or immediately after seed is sown. Sulphuric acid has been found very useful for conifers, as they are apparently especially tolerant of acid treatment. No method has yet been worked out to a point at which all of its details are entirely

satisfactory, though the acid treatment has now been in successful use for several years at some nurseries. At most nurseries, if the minimum effective quantity of acid is used, there is no need of any special precautions to prevent injury to the seedlings. It is not expected that any single treatment can be found that can be universally applied without change in details irrespective of differences in soil characters and in fungous flora.

(7) *Corticium vagum* and *Fusarium* spp. have been previously shown to be parasitic on pine seedlings. Different strains of *C. vagum* are found to vary considerably in their ability to cause damping-off, certain strains being consistently destructive and others much less active in tests conducted on different species of pine and several years apart. The differences in activity between strains were greater, and apparently rather more constant from one experiment to the next, than with Peltier's strains in his carnation experiments. Comparison of the results on pine with those of Edson and Shapovalov on potato gives some indication that strains vigorously parasitic on one of these hosts are likely to be parasitic on the other also.

(8) *Pythium debaryanum*, reported on many hosts and proved to be parasitic on few, is shown by repeated inoculation, reisolation, and reinoculation to be capable of causing the damping-off of seedlings of pine species. The identity of the fungus causing the damping-off of conifers with that attacking dicotyledons has been established by cross-inoculations as well as by morphological comparison. Inoculations on unheated soil are much less destructive than on heated soil. *Pythium debaryanum* has been obtained in culture from *Picea engelmanni*, *P. sitchensis*, *Tsuga mertensiana*, *Pinus banksiana*, *P. nigra austriaca*, *P. ponderosa*, *P. resinosa*, and *Pseudotsuga taxifolia*. In addition, fenugreek (*Trigonella foenum-graecum*), cowpea (*Vigna* sp.), and rice (*Oryza sativa*) are reported as apparently new hosts among the dicotyledons. In inoculations the fungus has been successfully used on *Pinus banksiana*, *P. ponderosa*, *P. resinosa*, and in a preliminary experiment on *Pseudotsuga taxifolia*. It had already been successfully used in preliminary inoculations on *Picea canadensis* by Hofmann (77).

Differences in parasitic activity on pine are found between different strains of *Pythium debaryanum*. These differences are not as large and partly for this reason their constancy is not quite as conclusively demonstrated as in the case of the strains of *Corticium vagum*.

(9) *Rheosporangium aphanidermatus* Edson, a parasite of radish and sugar beet, in many ways closely resembling *Pythium debaryanum*, has killed seedlings of *Pinus banksiana* and *P. resinosa* in certain experiments, and reisolations and reinoculations have been

made. The strain available is much less destructive to the pines than most of the *P. debaryanum* strains used, and as the fungus has never been isolated from coniferous seed beds it is not believed to be of any great importance in forest nurseries.

(10) *Phytophthora* sp. from *Pinus resinosa* seedlings has been successfully used in inoculation on *Pinus resinosa* and in a preliminary test on *P. ponderosa*. The strains available have been less destructive to the pines than *Pythium debaryanum* and the stronger strains of *Corticium vagum*. It is not common. Its relation to *Phytophthora fagi*, the European damping-off parasite of both conifers and dicotyledons, which has not been reported in this country, is being investigated.

(11) A fungus referred to *Pythium artotrogus*, also obtained from damped-off *Pinus resinosa*, has indicated a very low degree of parasitism on this host, even less than that shown by the *Rheosporangium* and *Phytophthora* strains. An addition is made to the statements in a previous paper concerning the ability of *Botrytis cinerea* to cause damping-off in conifers.

(12) The results of the cultural or direct examination of 742 disease foci in seed beds of various conifers are reported. *Pythium debaryanum* in the plate-culture examination method, considered more reliable than direct examination, appeared in 51 per cent of the foci from untreated beds, while *Corticium vagum* was found in 19 per cent. In foci in beds treated with various disinfectants, *P. debaryanum* was identified in 38 per cent of the foci and *C. vagum* in only 4 per cent. When direct microscopic examination was substituted for isolation, *C. vagum* was found on a larger proportion of the seedlings. It was not found at all in soil which had been heated. The relative ease with which it appears to be controlled by soil disinfection is in agreement with its poor adaptation for aerial distribution. It was found more commonly in cases in which the seedlings were directly examined than when cultures were made. In view of the fact that at least some of the *Corticium* foci extend rapidly and include very large numbers of seedlings, it seems that the *Corticium* may be as important as *P. debaryanum* in causing the damping-off of pines.

(13) *Fusarium* spp. have occurred more commonly in plate cultures than either of the above-mentioned fungi. Because little is known as to the parasitism of different species of this group on conifers, it is not possible to make any statement regarding the importance of the individual species. The evidence as a whole indicates so much importance for *Pythium debaryanum*, *Corticium vagum*, and for the *Fusarium* spp. considered as a group that no one of the three can be safely said to be more important than the others. None of the other fungi considered appear to be of real economic rank in the United States.

(14) In an inoculation experiment on the roots of pines 1½ months old, *Corticium vagum* and *Pythium debaryanum* were found able to cause the death of seedlings which had already developed rigid stems and to destroy the younger parts of the roots of seedlings which they were unable to kill. Indications were also obtained of similar but less vigorous action by *Fusarium moniliforme* and *F. ventricosum*.

(15) Data are given confirming the general belief that thick sowing favors the disease and indicating that soil acidity is, in general, unfavorable. Preliminary data on the relation of temperature and moisture to the disease are also presented. The parasitic activity of *Pythium debaryanum* in steamed soil was in one extensive test considerably decreased, following the inoculation of the soil with various saprophytes; this indicates both that competition of different fungi is a factor to be considered and that the inoculation of treated soil with saprophytes may sometimes prove of value in increasing the efficiency of heat disinfection. It is pointed out that with such a complex of parasites capable of producing identical symptoms on a number of different hosts, no relationship between environmental factors and the disease can be expected to hold in all cases.

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WM. A. TAYLOR, Chief



Washington, D. C.

PROFESSIONAL PAPER

February 6, 1922

INVESTIGATIONS OF THE WHITE-PINE BLISTER RUST.

By PERLEY SPAULDING, *Pathologist, Investigations in Forest Pathology.*

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SCOPE OF THE INVESTIGATIONS.

In a previous publication (131)¹ the writer collected data on the more practical aspects of the white-pine blister rust, as presented in European literature.

Experience has shown that the white-pine blister rust has come to North America to stay and that most careful and searching investigations must be maintained to enable us to cope with it at all successfully. Investigations in Europe have been carried on in a desultory way for 35 years. In North America they were begun less than 15 years ago. Really intensive work has been in progress for only about 5 years. Considerable new experimental work has been done in Europe since the appearance of this earlier publication. At various times since 1911 some of the more salient results of the investigation of *Cronartium ribicola* Fischer and the disease caused by it have been published (132 to 148, 180). During the years 1915 to 1919, inclusive, publication has fallen far behind the investigations.

¹ The serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

No attempt has ever been made to collate and summarize the results of all the experimental work. The mass of information is so large and so scattered that it is nearly impossible for a single individual, even now, to learn what has been done. This condition is certain to become more and more acute as the extensive and intensive researches now under way progress. Various States are taking up work on this disease, and the multiplication of workers can only result in confusion and unnecessary duplication of work unless the ascertained data are arranged and made available for all. This bulletin aims to present the available information so that the gaps in our knowledge may be readily perceived and new investigations planned to the best advantage.

The work of the Office of Investigations in Forest Pathology has been conducted under the direction and advice of the writer by the following persons: In 1915, G. F. Gravatt and Dr. G. R. Lyman; in 1916, Dr. R. H. Colley, G. F. Gravatt, and Miss M. W. Taylor; in 1917, Dr. R. H. Colley, G. B. Posey, G. F. Gravatt, Rush P. Marshall, and Miss M. W. Taylor; in 1918, Drs. R. H. Colley, H. H. York, L. H. Pennington, L. O. Overholts, A. S. Rhoads, T. C. Merrill, W. H. Snell, D. M. Benedict, and Miss M. W. Taylor; in 1919, Drs. R. H. Colley, H. H. York, and L. H. Pennington, D. M. Benedict, J. E. Lodewick, W. H. Snell, P. R. Gast, Miss A. E. Rathbun, and Miss M. W. Taylor. Dr. G. G. Hedgcock made a comparative study of *Cronartium occidentale* and *C. ribicola* on Ribes on Block Island, R. I., in 1919.

The work of Dr. L. H. Pennington, D. M. Benedict, and J. E. Lodewick, in 1919, was maintained in formal cooperation with the New York State College of Forestry at Syracuse University.

The endeavor has been to show plainly in this bulletin who did each piece of work without entering into details to an objectionable extent.

The writer thanks the following people for unpublished data which have been placed at his disposal: Mr. W. A. McCubbin, formerly of Canada; Dr. Ed. Fischer, of Switzerland; Dr. A. B. Borthwick, of Scotland; Mr. A. D. Cotton, of Kew Gardens, England; Prof. L. Mangin, Museum of Natural History, Paris; Prof. F. Kølpin Ravn and Mr. J. Lind, of Denmark; Dr. L. O. Kunkel and Mr. W. Stuart Moir, of this country.

The writer and his collaborators are indebted for material for experimental use to the Arnold Arboretum of Harvard University; the Dominion of Canada Central Experimental Farms; the Park Board of Rochester, N. Y.; the Conservation Commission of the State of New York; the Office of Horticultural and Pomological Investigations and the Forest Service, of the United States Department of Agriculture. The Office of Blister-Rust Control has contributed

data, especially toward that appearing in the chapter on control, Table V, and the list of *Ribes* species infected in the different States. Much difficulty has been encountered in getting satisfactory translations of articles published in the Japanese, Russian, Dutch, Swedish, Norwegian, and Danish languages. Dr. E. P. Meinecke has very kindly translated most of the Scandinavian and Danish articles. Mr. Rush P. Marshall and Miss M. W. Taylor, have aided in checking and collating the extensive data here presented.

In this bulletin the behavior of *Cronartium ribicola* is given with considerable detail. So far as is now known, it agrees essentially with the Uredinales in general in its life history and physiology. This is the first species of *Cronartium* to be very intensively investigated, and as a representative of this important group of forest-tree fungi, a detailed knowledge of its life history must form the basis for the institution of new methods of management of white-pine forests.

ORIGIN AND DISTRIBUTION OF CRONARTIUM RIBICOLA.

Some writers (76, 90) have believed that *Cronartium ribicola* went to Europe from America on *Ribes aureum*, that host being associated with it (but not exclusively) in the earlier discoveries of the disease in Europe. Magnus, who was of this opinion at first (90), seems to have completely rejected this theory and now believes that the disease came from western Siberia and the Swiss Alps, where it is supposed (26, 39, 40, 93, 130, 174) to have been endemic on *Pinus cembra*. In 1842 Klotzsch issued in the *exsiccatae* entitled "Herbarium vivum mycologicum, No. 490," a specimen labeled "*Uredo ribicola*" collected by Lasch at Driessen. Specimens have not been seen by the writer, and there is some uncertainty whether or not this is actually the uredinial stage of *Cronartium ribicola*. Sydow (155) gives it as a synonym of *C. ribicola*, but he is the only author known to the writer who does so.

Cronartium ribicola was first certainly found by Dietrich (27) in the Baltic provinces of Russia in 1854. He found it upon *Ribes nigrum*, *R. "rubrum,"* and *R. "palmatum,"* and also upon *Pinus strobus*, although at that time it was not known that the two forms were stages of a single fungus. So far as can be determined from scientific literature, it was not again noted until 1861 in Finland (81), 1865 in East Prussia (76), and 1869, when Eriksson (31) found it in Sweden on *Ribes nigrum*, and Hisinger (54) noted the first outbreak on pines in Finland. It had attacked *Pinus strobus* trees 30 years old and killed them. In 1883 Rostrup (115) reported an outbreak in Denmark on *Pinus strobus* trees 20 to 30 years old. It was evidently then generally spread over that country. Still later, Klebahn (62, 63) and Tubeuf (169) record it as generally distributed over

Germany, and soon it had spread over the northern countries of Europe (91, 92, 93). It seems to the writer that this was an instance of the introduction of a foreign disease into Europe and its destructive spread over most of that continent (39, 40). The fact that *Pinus strobus* had been grown extensively in Europe since its introduction there in 1705 (5), but was not known to have this disease until about 1855, in the light of our experience with this and other introduced plant diseases in North America, shows that this was a new disease which had reached Europe probably years before its discovery.



FIG. 1.—Outline map of the Old World, showing the approximate distribution of *Pinus cembra* (oblique hatching) and of its variety *pumila* (vertical hatching) together with the known distribution of *Cronartium ribicola* (black dots). Tree distribution furnished by the Forest Service, United States Department of Agriculture.

It is not certain that *Cronartium ribicola* is a native of the Swiss Alps (174). Schellenberg (123), in 1903, found *Cronartium ribicola* on a single 15-year branch of a tree of *Pinus cembra* about 200 years old in the Engadine Valley, Switzerland. He believed that the fungus was native there on this host. Yet this is the first known finding of the fungus on pine in that region. Ribes diseased with it were found there in 1895 (39, 123), showing it to be established in that locality then. It seems to the writer that the circumstances point plainly to the fungus having come into Switzerland some time previously, and that it is not endemic there; else it would have been

found much earlier, and more of it would have been found since then. Fischer (40) found the disease in 1915 spreading into western and northern Switzerland from without.

It is generally supposed that *Pinus cembra* (26, 70, 93, 97, 98, 123) is the original pine host of this fungus. Figure 1 shows the distribution of *P. cembra* and its variety *pumila* in Europe and Asia. *Cronartium ribicola* is reported from Asia as follows: In 1879, from

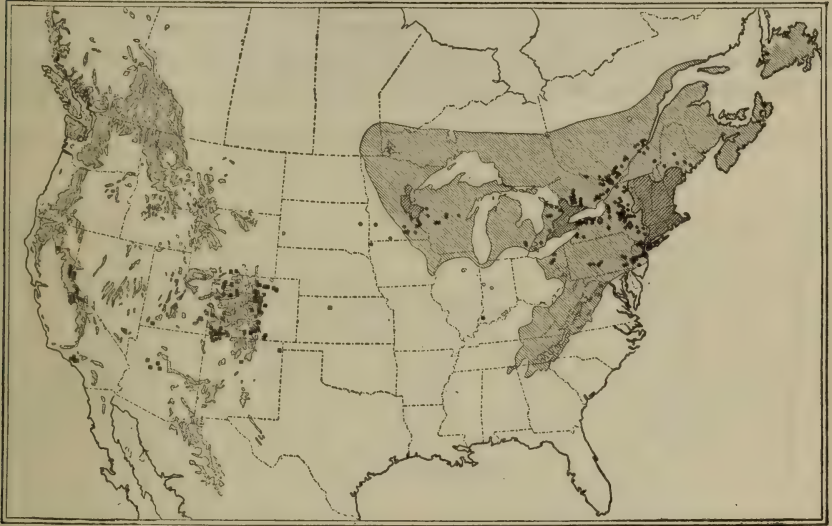


FIG. 2.—Outline map of the United States, showing the known distribution of *Cronartium ribicola* and *C. occidentale* in North America to January 1, 1920. Localities for *Cronartium occidentale* are shown by black squares in the Pacific coast and Rocky Mountain regions, the easternmost point being in western Kansas. This is where it was found in 1892, but it has not been seen there since. Localities for *C. ribicola* are indicated by double cross hatching and black dots, nearly all being north of the Potomac and Ohio Rivers and east of the Mississippi River. Four points in southwestern Minnesota, eastern South Dakota, and northern Iowa were found to be due to diseased nursery stock which was shipped in. It is believed that the disease now has been eradicated in these outer western localities. The natural distribution of the eastern white pine is shown in the large cross-hatched area mostly east of the Mississippi River. The cross-hatched areas shown on the western half of the map indicate the known distribution of the western white pines. The piñon pines range as far north as southern Idaho but at altitudes different from those of the white pines. *Cronartium ribicola* is limited to the eastern white-pine area and was not known in North America until 1906. In most places where now found it has been traced to diseased imported white-pine stock. *Cronartium occidentale* is limited to that part of the western white-pine area in which piñon pines are native, where it appears also to be native. The two fungi are separated by a strip of prairie country about 500 miles wide. Distribution of the pines furnished by the Forest Service, United States Department of Agriculture. Distribution of *Cronartium occidentale* furnished by Messrs. Bethel and Posey, of the Offices of Investigations in Forest Pathology and of Blister-Rust Control, respectively.

Bolschaja Inja River (131, 161); also from Tomsk and Minusinsk, Siberia (131). Quite recently it has been reported from Sakhalin Island and from Sapporo, Japan (156). Tulasne (175) in 1854 reported a *Cronartium* on *Ribes*, probably in India. Clinton has announced (13) the finding of *Cronartium ribicola* on dried herbarium specimens of *Ribes* collected by Wilson in the western part of the Province of Hupeh, China, in 1900.

To sum up briefly: *Pinus cembra*, the probable original pine host, ranges across northern Asia; and the fungus is reported from western, eastern, and central Asia, in some places where it may easily be endemic.

In North America, *Cronartium ribicola* was first found in 1906 at Geneva, N. Y. (3, 150). Later findings have indicated that it was here in the Northeastern States as early as 1898 (108, 136, p. 6). It might have been in North America a few years, but not many, before that date. This is supported by Clinton (13), who unsuccessfully examined specimens of *Ribes* which are in some of the larger herbaria of the eastern part of this country. The writer has supplemented

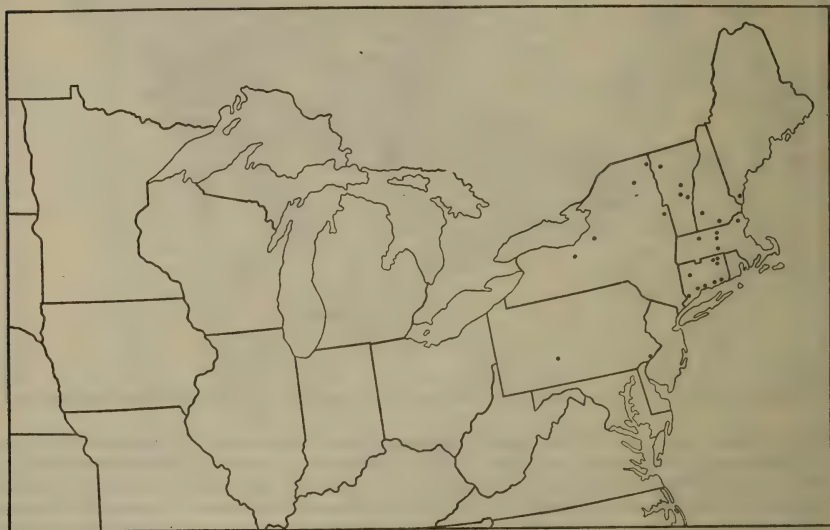


FIG. 3.—Outline map of the northeastern part of the United States, showing (by black dots) the known distribution of white-pine blister rust in North America to and including 1909.

Clinton's work by examining the *Ribes* specimens in several additional herbaria. These include the Pringle herbarium at the University of Vermont and the local collections of the University of Vermont; of Dartmouth College; of President Ezra Brainerd, of Middlebury College; of Mr. C. A. Weatherby, of East Hartford, Conn.; and of Mr. C. H. Bissell, of Southington, Conn. The most notable herbarium examined was that of the Boston Society of Natural History, which contains many New England collections made in the early years of the nineteenth century. Moreover, such keen fungus collectors as Farlow, Seymour, G. P. Clinton, Peck, Ellis, George Clinton, Stewart, and many others, never collected *Cronartium ribicola* until 1906, showing that it is a recent immigrant. Since 1909, when it was first found in North America on white pines, *Cronartium ribicola* has spread until it is firmly estab-

lished in New England, New York, Wisconsin, Minnesota, and Canada.

It has been known since 1892 that there was a fungus on *Ribes* in the West much resembling *Cronartium ribicola*, but until 1917 its alternate stage on pines was unknown. In that year the Office of Investigations in Forest Pathology began work upon this western fungus, which was soon found to have an alternate stage on *Pinus edulis* and *P. monophylla* in Colorado and Arizona (50, 114) and was named *Cronartium occidentale*. Its distribution and that of *C. ribicola* as known to January 1, 1920, is shown on the map (fig. 2). See figures 3 to 12 for the progress of *C. ribicola* by years from 1909 to

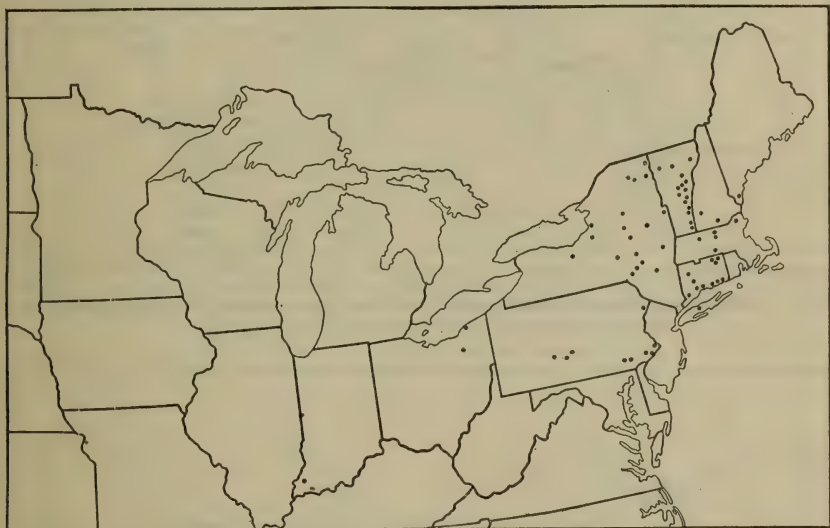


FIG. 4.—Outline map of the northeastern part of the United States, showing (by black dots) the known (cumulative) distribution of white-pine blister rust in North America to and including 1910.

1918, inclusive. *Cronartium occidentale* is found in localities where it could hardly be an introduction, as the Ute Indian Reservation in southwestern Colorado, where it was found by Bethel in 1897; also in the Mesa Verde region, where no cultivated *Ribes* or pines have ever been introduced. *Ribes aureum* is native in the Rocky Mountain region and is a favorite host for *Cronartium occidentale* as well as *C. ribicola*.

Since *Ribes aureum* was intimately associated with *Cronartium ribicola* in its earlier known occurrences in Europe, an inquiry has been made into the possibility of the fungus being American in origin and its being introduced into Europe on *R. aureum* when that plant was first sent there. The facts thus far determined are² that *R. aureum*

² Spaulding, Perley. *Ribes aureum* not an original host of *Cronartium ribicola*. In manuscript. To be published in *Phytopathology*.

is definitely stated to have been introduced into England (the probable first point of introduction in Europe) in 1812 by Thomas Nuttall. Evidently Nuttall collected the seeds of this plant while on a botanical

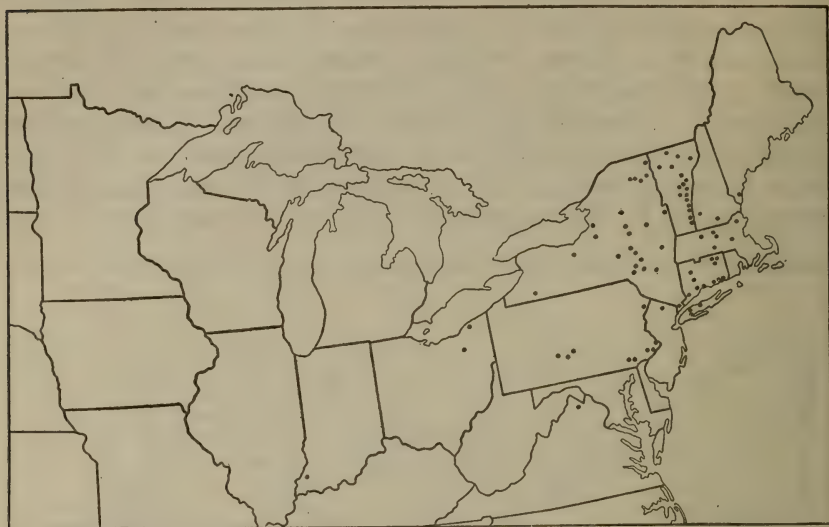


FIG. 5.—Outline map of the northeastern part of the United States, showing the known distribution of white-pine blister rust in North America to and including 1911.

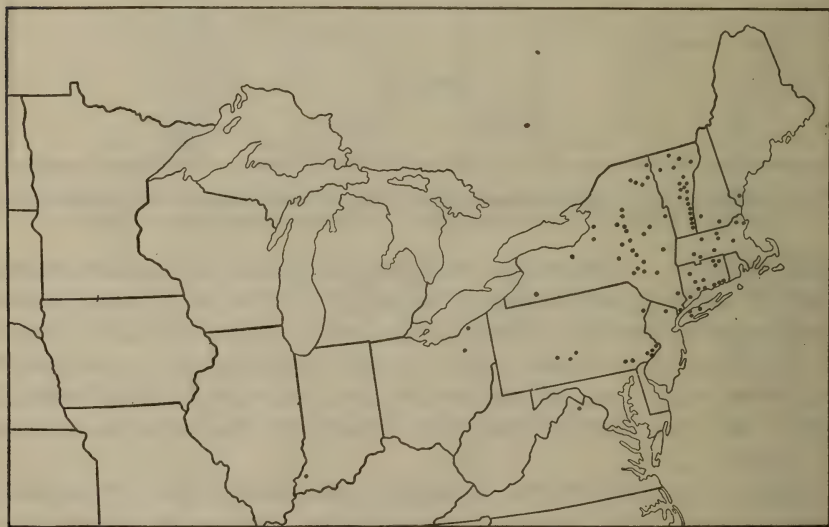


FIG. 6.—Outline map of the northeastern part of the United States, showing (by black dots) the known distribution of white-pine blister rust in North America to and including 1912.

trip in 1811 with John Bradbury up the Missouri River to a point in the eastern part of Mercer County, N. Dak. His material must have been shipped quite promptly to England, as Fraser's nursery at

Chelsea, London, in 1813, offered for sale plants "collected in Upper Louisiana and principally on the River Missouri, North America." There is reason to believe that these were Nuttall's plants. The

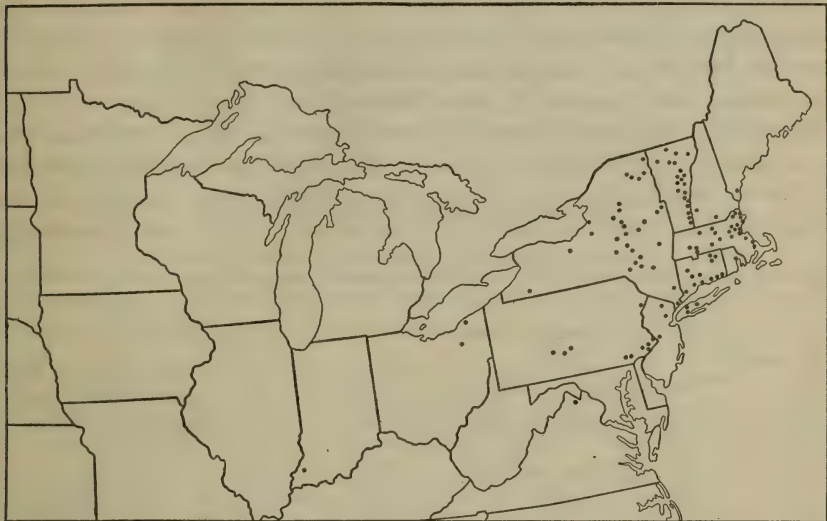


FIG. 7.—Outline map of the northeastern part of the United States, showing (by black dots) the known distribution of white-pine blister rust in North America to and including 1913.

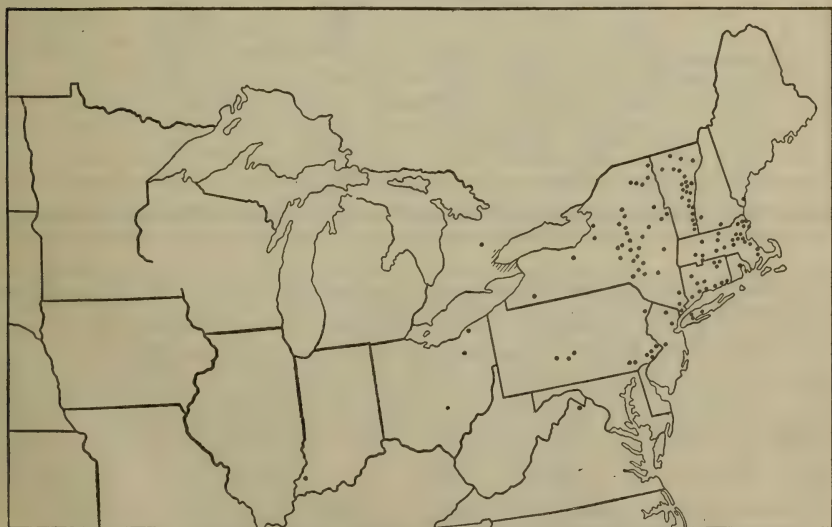


FIG. 8.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1914. The cross hatching in this and the following maps indicates areas which are generally infected.

plant of interest to us is listed as *Ribes longiflorum*, a new species from the Missouri. This is now known as *R. odoratum* Wendland, which is the common form generally cultivated in the eastern United

States under the name *R. aureum*. This appears to be the form most common in cultivation in Europe, but the true *R. aureum* of the Rocky Mountain region and the plains of the Columbia was evidently introduced there soon after *R. odoratum*, if not at about the same time. Pursh may have referred to living plants of true *R. aureum* but we have no means of determining this. Lindley in 1828 made the new species *R. tenuiflorum* (now *R. aureum*) and says "Clt. 1812," evidently meaning "cultivated in 1812." He had this so definitely distinguished from our *R. odoratum* that his statement is fairly conclusive that *R. aureum* actually was introduced into England the same year as was *R. odoratum*. The agent introducing

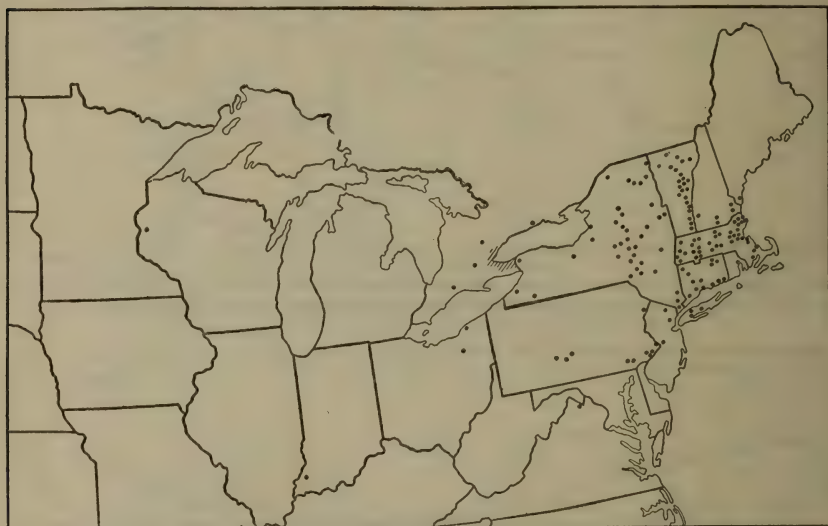


FIG. 9.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1915.

R. aureum can not be determined beyond question. There appears to be little doubt, because of the difficulty of communication at that time, that both plants were carried from their native regions to the eastern part of this country in the form of seeds. Cuttings may have been sent to Europe but it is more likely that seeds were sent. Seeds would not be likely to transmit a rust which does not attack the fruit. It does not seem possible that a fungus like *Cronartium ribicola* could be carried to Europe on these plants without becoming established in the Eastern States. Moreover, these species of *Ribes* apparently were introduced into Great Britain first. The fungus was not known in Great Britain until 1892, long after it was prevalent in other northern European countries. It appears that *Cronartium ribicola* was carried to Great Britain on infected white pines from northwestern Germany. The evidence appears to show that *Cro-*

nartium ribicola attacked *Ribes aureum* and *R. odoratum* after they reached Europe. Their susceptibility also indicates that they are not original hosts of the fungus.

Summing up the evidence available, it appears (1) that *Cronartium ribicola* is Asiatic in origin; (2) that it spread in the early 1800's into western Russia, whence it eventually spread well over Europe (41); (3) that it was brought to North America in young trees of *Pinus strobus*; and (4) that comparative studies (50) show that *Cronartium occidentale* is distinct.

HOSTS OF CRONARTIUM RIBICOLA.

Pines Infected and Likely to Become Infected.

Cronartium ribicola has attacked 11 of the white pines in the countries, Provinces, and States indicated in the following list:

Pinus aristata Engelm. in England (20a).

ayacahuite Ehrenb. in Scotland and England.³

cembra L. in Russia (58, 93), Switzerland (39, 40, 123, Germany (72, 77, 174, 177),

U. S. A. (Mass., Minn.).⁴

excelsa Wall. in Denmark (120), Germany (99), U. S. A. (Mass.).

flexilis James in Germany (173), Sweden,⁵ U. S. A. (Mass., Minn., Iowa).

koraiensis Sieb. and Zucc. in Sweden.⁵

lambertiana Douglas in Belgium (101), Germany (62, 173).

monticola Douglas in Belgium (101), England (79), Germany (70).

parviflora Sieb. and Zucc. in U. S. A. (Mass.).

peuce Gris. in Germany (173).

strobus L. in Austria-Hungary (178), Belgium (70), Denmark (81, 115, 117, 119, 120), Finland (54, 83), Switzerland (40), France (70), Germany (70), Great Britain (111), Holland (70), Ireland (42), Norway (70), Russia (27, 58, 120), Siberia (161), Sweden (131⁵), Canada—Ontario (23, 56) and Quebec (107, 121), U. S. A. (Conn., Ind., Iowa, Maine, Mass., Mich., Minn., N. H., N. J., N. Y., Ohio, Penn., R. I., S. Dak., Vt., Va., Wis.). The fungus has occurred in a number of these States only on diseased pines shipped from outside points.

In every case the disease attacked these pines naturally in outbreak areas of Europe and North America and is not known to attack any of the pitch pines, although some of them have been present in infected areas. Whenever the other white pines are continuously exposed to the fungus they will be likely to develop the disease. The blister rust was first found on the different species of pines as follows:

Pinus strobus. Russia in 1854.

lambertiana. Germany in 1887.

cembra. Russia in 1890.

monticola. England in 1898.

excelsa. Denmark in 1902.

aristata. England in 1907.

Pinus ayacahuite. Great Britain in 1908.

flexilis. Germany in 1914.

peuce. Germany in 1914.

parviflora. United States in 1916.

koraiensis. Sweden in 1920.

³ Communicated in a private letter from Dr. A. B. Borthwick, of Scotland.

⁴ The statements concerning occurrences in North America are based on records and specimens in the Office of Investigations in Forest Pathology.

⁵ Private letter from W. Stuart Moir, Office of Blister-Rust Control.

Sudworth (154) recognizes eight species of the white pines (exclusive of the piñon pines) for North America (fig. 2) but does not treat those of the Old World. Shaw (126), who treats the pines of the world, also recognizes eight North American species of white pines. He is, therefore, taken as the authority for the pines in this bulletin. The white pines of the world are grouped by Shaw as follows:

Genus *Pinus*.

Section Haploxylon.

Subsection *Cembra*.

Group I. *Cembræ*.

koraiensis +.

cembra +.

albicaulis.

Group II. *Flexiles*.

flexilis +.

armandi.

Group III. *Strobi*.

ayacahuite (or *strobiformis*) +.

lambertiana +.

parviflora +.

peuce +.

excelsa +.

monticola +.

strobis +.

Subsection *Paracembra*.

Group IV. *Cembroides*—piñon pines.

Group V. *Gerardianæ*—piñon pines.

Group VI. *Balfourianæ*.

balfouriana.

aristata +.

In examining the above synopsis, note the grouping of the known susceptible species (which are indicated by +) especially in the first three groups which make up the subsection *Cembra*. Investigations of outbreak areas in Europe where the various species of pine have been present might yield on this point most interesting and valuable information which can be obtained in no other way.

Inoculations of *Cronartium Ribicola* on Pines.

Klebahn (68, 71) appears to be the first European investigator who has inoculated pines with *Cronartium ribicola* and who has published his results. He inoculated young *Pinus strobus* trees with pycnospores, but with no success (70, p. 387). Inoculations made by him with sporidia in 1888 were rendered worthless because the pines were probably infected naturally before the test was made (71). On August 27, 1903, Klebahn (71) made inoculations on two young *Pinus strobus* trees by suspending telia-bearing leaves of *Ribes nigrum* above the trees and covering them with a large bell jar. On June 19,

1904, the pines were examined. At that time some of the new shoots bore abnormal leaves of a juvenile type singly, instead of in fives. The new twigs were abnormally pale in color. Many of the leaves of the growth of the previous year were spotted with yellow through their entire thickness. These yellow spots were especially plentiful near the base of the leaves. Microscopic examination showed abundant mycelium to be present in the yellow areas. Later pycnia developed on the twigs near the bases of the spotted leaves.

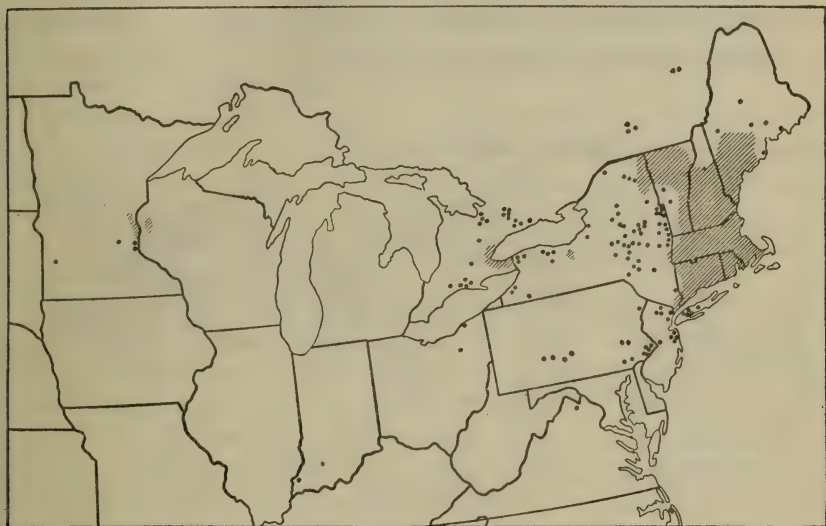


FIG. 10.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1916.

In 1914, Tubeuf (174) inoculated trees of *Pinus strobus*, *P. lambertiana*, *P. cembra*, *P. cembroides*, *P. excelsa*, *P. peuce*, *P. parviflora*, *P. flexilis*, and *P. montezumae* with sporidia of *Cronartium ribicola* under controlled conditions. In 1917, æcia were produced on some of the *P. strobus*. Yellow spots were produced on the leaves of *P. lambertiana*, but no further development of the fungus occurred. Spots which were doubtfully caused by the fungus were noted on *P. cembroides*. No other species became infected. Infections were produced directly on the juvenile leaves, on mature leaves, and through the epidermis of the lengthening buds of the young shoots.

In North America, the writer seems to have been the first to inoculate successfully young *Pinus strobus* trees with sporidia (133, 134). The inoculations were made both with and without wounds in the young bark, telial columns being used for inoculum. Pycnial drops were produced by one tree unwounded and by one which was

wounded. At this stage slugs ate the infected bark and prevented further development of the fungus. In 1916 and in 1917, 150 æciospore inoculations were made on leaves, on twigs of various ages, and on branches of *P. strobus* trees up to six years. No infections have resulted.

Clinton and Miss McCormick (14, 15), have published details of successful inoculations, through the leaves, with sporidia on *P. strobus*. Inoculations were unsuccessful upon leaves of *P. excelsa*, *P. flexilis*, *P. koraiensis*, and *P. cembra*; also on the pitch pines *P. resinosa*, *P. sylvestris*, *P. densiflora*, and *P. austriaca*. Yellow spots



FIG. 11.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1917.

have been secured on leaves of *P. lambertiana*, *P. pinea*, and *P. sabiniana*.

Cross-inoculations that are known to have been successful up to July 1, 1920, are shown in Plate I.

Species of *Ribes* That Have Been Infected Naturally.

In Europe and North America, where extensive outbreaks of *Cronartium ribicola* have occurred, a considerable number of species of *Ribes* have been found naturally infected by the fungus. Practically all of the cultivated species and most of the wild ones take the disease in every extensive outbreak area. More species have been found infected in Europe than in North America, because outbreaks have been discovered there in botanical gardens, parks, and nurseries

where extensive collections of the different species of *Ribes* were located, and hence more species have been subjected to attack.

In Europe the following species have become infected naturally: *Ribes aciculare* Smith, *R. affine* H. B. K., *R. alpinum* L., *R. americanum* Mill., *R. aureum* Pursh, *R. biebersteinii* hybrid, *R. bracteosum* Douglas, *R. cynosbati* L., *R. divaricatum* Douglas, *R. glandulosum* Grauer, *R. gordonianum* hybrid, *R. hirtellum* Michx., *R. irriguum* Douglas, *R. menziesii* Pursh, *R. missouriense* Nuttall, *R. multiflorum* Kit., *R. nigrum* L., *R. niveum* Lindl., *R. odoratum* Wendl., *R. oxycanthoides* L., *R. petraeum* Wulf., *R. reclinatum* L., *R. rotundifolium* Michx., *R. rubrum* L., *R. sanguineum* Pursh, *R. setosum* Lindl., *R. triste* Pallas, *R. vulgare* Lam.

The names of species of *Ribes* of North America are based on the treatment of the North American species by Coville and Britton in "North American Flora" (22) and of species of the other continents on that of Janczewski in "Monographie des Groseilliers, *Ribes* L." (60). For the sake of convenience the currants and gooseberries are kept in the single genus *Ribes*.

As recently as 1914 (136) the fungus had not been found in North America attacking any wild species of *Ribes*. Since then it has been found attacking an increasing number of wild *Ribes*, as additional species are subjected to infection by the spreading and multiplication of the known outbreak areas and as new ones are discovered. To date it is known to have been found attacking naturally the following species of *Ribes* in the States and Provinces named:

Ribes americanum (*floridum*).—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, New York, Wisconsin, Minnesota, and Ontario.

cynosbati.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Wisconsin, Minnesota, and Ontario.

glandulosum (*prostratum*).—Maine, New Hampshire, Vermont, Massachusetts, Connecticut, New York, Wisconsin, Minnesota, and Ontario.

hirtellum.—Maine, New Hampshire, Massachusetts, New York, Wisconsin, and Minnesota.

irriguum.—New York.

lacustre.—Maine, New Hampshire, New York, and Wisconsin.

missouriense.—New York, Minnesota, and Wisconsin.

nigrum.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Wisconsin, Minnesota, Ontario, and Quebec.

odoratum.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Minnesota, and Ontario.

reclinatum (*grossularia*).—Maine, Vermont, Massachusetts, New York, Wisconsin, Minnesota, and Ontario.

rotundifolium.—New York.

triste.—Maine, New Hampshire, Massachusetts, Wisconsin, Minnesota, and Ontario.

vulgare (*rubrum*).—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Wisconsin, Minnesota, and Ontario.

Inoculations of *Cronartium ribicola* on *Ribes*.

In 1888, Klebahn (63, 64) made the first known successful inoculations of this fungus on *Ribes*. Since that time a number of inoculations have been made in Europe by Klebahn (65, 66, 67, 68, 69, 70), Wettstein (70), Rostrup (118, 119, 120), Schøyen (124), Eriksson (31, 33), Tubeuf (167), Hennings (53), Sorauer (129), Tranzschel (92), Neger (100), Ewert (36, 37), Naumann (36), and Jaczewski (58, 59). The published accounts of most of these experiments are very fragmentary and lack many essential details. In fact the attitude of the European investigators seems to have been that of mild interest in a new fungus rather than that of intensive study of a new parasite and of the destructive disease caused by it.

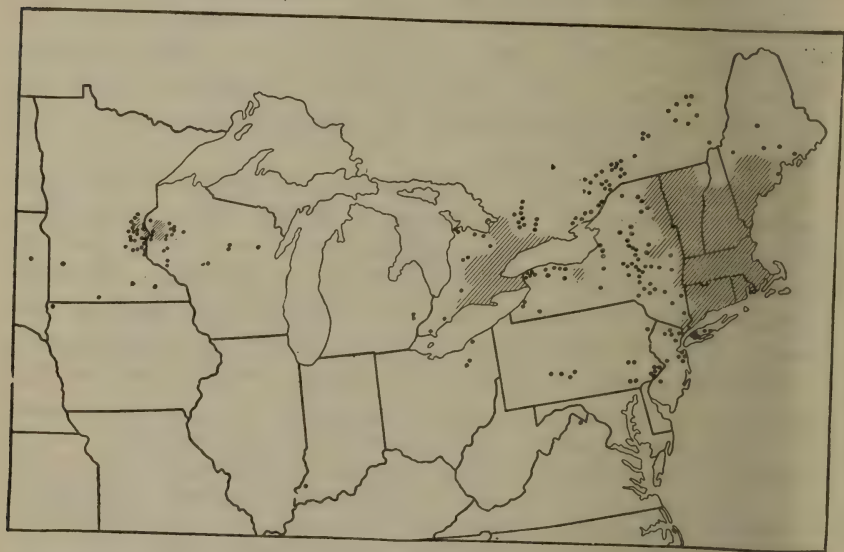


FIG. 12.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1918. For distribution to the end of 1919, see figure 2.

Since the summer of 1909 the writer and his collaborators have made repeated tests under controlled and natural conditions of all species and of all varieties of the cultivated species of *Ribes* that could be obtained. In the earlier work complete records were not kept, but in the last few years the records were made to cover all points likely to be of value. Hundreds of inoculations have been made on the more susceptible species to keep the fungus growing in vigorous condition, without records being made. It was felt that greenhouse tests alone were not dependable for susceptibility data. Therefore, in 1916, a test plat was located upon Block Island, R. I. This island lies 12 miles from the nearest projecting point of the mainland and 15 miles or more from the main shore line. No white pines are on the island and but few cultivated *Ribes*. It was chosen

Pinus:-

Ribes:-

Ribes:-

strobis

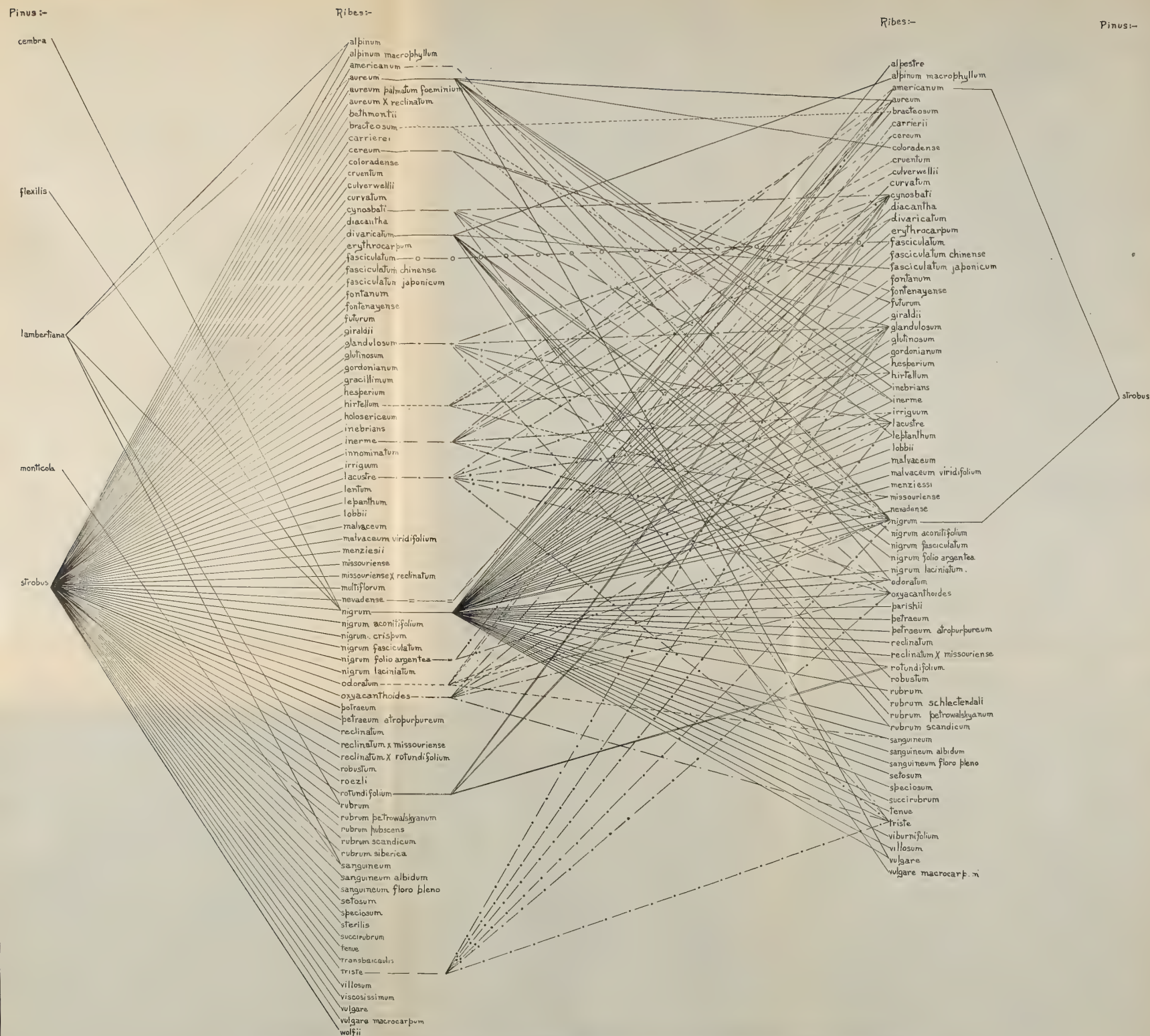


DIAGRAM SHOWING CROSS-INOCULATIONS MADE WITH CRONARTIUM RIBICOLA TO JANUARY, 1921, INCLUDING THOSE MADE BY EUROPEAN INVESTIGATORS.

Drawn by Rush P. Marshall.

as the safest place for such work at that time. In midsummer, 1916, before the disease was fairly started on the bushes on the island, it was found to be pretty generally distributed over New England on Ribes, having plainly been widely disseminated there before the Block Island experiment was started. Conditions on the island are not very favorable for Ribes and are decidedly unfavorable for white pines. *Pinus nigra* var. *austriaca* is the only pine seen on the island, and it occurs only in protected hollows.

Table I presents the general results of tests made in the greenhouse where inoculations were made with both æciospores and urediniospores. A preliminary statement has been published, giving the earlier results of this work (147). This table is to be interpreted as follows:

In the columns headed "Susceptibility," a single cross (×) means slight infection, two crosses (××) mean a medium degree of infection, and three crosses (×××) mean heavy infection.

There are no means of knowing what degree of susceptibility was indicated by the experiments of European and Canadian investigators, whose results are included in section 1 of Table I. The foreign experimenters are first listed alphabetically under each species of Ribes, then the work done in this country is given in a similar manner. The varietal tests (sections 2 to 4 of Table I) are wholly the work of the Office of Investigations in Forest Pathology, there being practically no data in foreign literature on inoculations of horticultural varieties.

In numerous cases but a single test has been made as yet; but the general behavior of the tested plants in the spread of the fungus, the type of its fruiting, etc., during the rest of the season are considered in the final estimate of susceptibility. When a single test has been made under favorable conditions, it is believed that the results are fairly indicative of the susceptibility of the species or variety tested. Many tests were made under conditions known to be adverse, and the negative results are largely due to this cause alone. But these tests are given with the others to give some idea of what has been done. Scanty numbers of tests are often due to the Ribes stock dying before a second test could be made. This is true of many cuttings which made a weak start and did not survive potting.

In sections 2 to 4 of Table I, relating to the varieties of Ribes, an attempt has been made to use varietal names that are intelligible to horticulturists as accepted by the American Pomological Society. Acknowledgment is made to the Office of Horticultural and Pomological Investigations of the United States Department of Agriculture for help in this matter. In some cases varietal names are given which are considered to be synonyms of others in the list; but in such cases the stocks used under the two names were evidently different. Varieties and even species of Ribes supplied by nurserymen are often other than what they purport to be, and in some cases they are mixtures of two or more distinct things; hence, the varietal names can not be taken as being absolutely reliable.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, showing data on susceptibility in the greenhouse and out of doors on Block Island, R. I.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 1.—Species of <i>Ribes</i> . ^a					SEC. 1.—Species of <i>Ribes</i> —Contd.				
R. alpestre:					R. diacantha:				
Gravatt.....	2	2	×	×	Gravatt.....	1	2	}	×
R. alpinum:					Taylor.....	0	2		
Klebahn.....	1	1			R. divaricatum:				
Neger.....	0	1			Rostrup.....	1	1		
Sorauer.....	1	1			Tubeuf.....	1	1		
Gravatt.....	0	1	}	0	Gravatt.....	11	18	}	×
Marshall.....	0	2			Spaulding.....	3	3		
Taylor.....	0	2			Taylor.....	2	2		
R. alpinum macro-					R. erythrocarpum:				
phyllum:					Gravatt.....	2	2	×	
Rhoads.....	0	1	}	0	R. fasciculatum:				
Spaulding.....	0	1			Gravatt.....	4	4	}	×
R. amarum:					Merrill.....	1	2		
Taylor.....	1	1	×	×	Spaulding.....	1	3		
R. americanum:					Taylor.....	20	20		
Sorauer.....	1	1			R. fasciculatum chi-				
Gravatt.....	4	4	}	×	nense:				
Spaulding.....	2	2			Gravatt.....	1	1	}	×
Taylor.....	6	6			Merrill.....	1	3		
York.....	1	1			Spaulding.....	6	6		
R. aureum:					R. fasciculatum jap-				
Klebahn.....	4	4			onicum:				
Sorauer.....	1	1			Spaulding.....	2	2	×	
Tubeuf.....	1	1			R. fontanum:				
Gravatt.....	13	13	}	×	Colley and Tay-	1	1	}	×
Hedgecock.....	1	1			lor.....	1	1		
Marshall.....	5	6			Gravatt.....	3	3	×	
Spaulding.....	6	6			R. fontenayense:				
Taylor.....	27	28			Gravatt.....	1	1		
R. aureum "palma-					R. futurum:				
tum foeminum":					Gravatt.....	1	1	}	×
Spaulding.....	1	2	×		Merrill.....	1	1		
R. aureum × recli-					Spaulding.....	1	1		
natum:					Taylor.....	1	1		
Gravatt.....	1	1	×		R. giraldii:				
R. bethmontii:					Gravatt.....	1	1	×	
Spaulding.....	1	2	×		R. glandulosum:				
R. bracteosum:					Lyman.....	1	1	}	×
Gravatt.....	3	4	×	×	Snell.....	6	6		
R. carrierei:					Spaulding.....	1	1		
Gravatt.....	10	11	×	×	Taylor.....	2	2		
R. cereum:					R. glutinosum:				
Gravatt.....	2	2	}	×	Gravatt.....	1	3	}	×
Marshall.....	2	2			Spaulding.....	2	2		
Spaulding.....	6	7			R. gordonianum:				
Taylor.....	2	3	×		Gravatt.....	3	4	}	×
R. coloradense:					Spaulding.....	1	1		
Spaulding.....	1	1	}	×	R. hesperium:				
Taylor.....	2	2			Gravatt.....	1	2	}	×
R. cruentum:					Merrill.....	1	1		
Gravatt.....	5	7	×		Taylor.....	1	1		
R. culverwellii:					R. hirtellum:				
Gravatt.....	3	4	}	×	Gravatt.....	7	11	}	×
Marshall.....	3	3			Lyman.....	2	2		
R. curvatum:					Spaulding.....	2	4		
Gravatt.....	1	4	}	×	Taylor.....	2	3		
Marshall.....	1	3			R. hirtellum × re-				
Spaulding.....	1	1			clinatum:				
Taylor.....	1	1	×		Hedgecock.....	2	2	×	
R. cynosbati:					R. holosericeum:				
Tubeuf.....	1	1			Gravatt.....	1	1	×	
Gravatt.....	3	4	}	×	R. inebrians:				
Hedgecock.....	1	1			Hedgecock.....	4	4	×	
Lyman.....	2	3			R. inerme:				
Spaulding.....	2	2			Gravatt.....	15	17	}	×
					Hedgecock.....	2	2		
					Spaulding.....	2	3		
					Taylor.....	4	4		

^a Summary of tests made in foreign countries and in America.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, etc.—Continued.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 1.—Species of <i>Ribes</i> —Contd.					SEC. 1.—Species of <i>Ribes</i> —Contd.				
<i>R. innominatum</i> :					<i>R. nigrum</i> "fasciculatum":				
Spaulding.....	1	4	} XX	-----	Rhoads.....	1	1	XXX	-----
Taylor.....	2	2			<i>R. nigrum</i> "folioargentea":				
<i>R. irriguum</i> :					Spaulding.....	1	1	} XXX	-----
Gravatt.....	2	2	X	X	Taylor.....	2	2		
<i>R. lacustre</i> :					<i>R. nigrum</i> "lacinia-tum":				
Gravatt.....	8	11	} XX	X	Sorauer.....	1	1	-----	-----
Spaulding.....	2	2			<i>R. odoratum</i> :				
Taylor.....	3	3			Gravatt.....	25	29		
<i>R. leptanthum</i> :					Hedgecock.....	6	6		
Spavatt.....	4	5	} b X	-----	Marshall.....	1	2	} XX	XX
Spaulding.....	1	1			Spaulding.....	3	3		
Taylor.....	4	7			Taylor.....	15	15		
<i>R. lobbian</i> :					<i>R. oxyacanthoides</i> :				
Gravatt.....	2	4	X	X	Tubeuf.....	0	1	-----	-----
<i>R. malvaceum</i> :									
Gravatt.....	1	4	} X	-----	Gravatt.....	2	2		
Spaulding.....	0	3			Lyman.....	0	1		
<i>R. malvaceum viri-difolium</i> :					Merrill.....	1	1	} XX	-----
Gravatt.....	1	4	} X	-----	Spaulding.....	1	1		
Merrill.....	1	2			Taylor.....	2	2		
Spaulding.....	0	3			<i>R. parishii</i> :				
<i>R. menziesii</i> :					Taylor.....	7	7	XX	-----
Gravatt.....	1	1	} XX	X	<i>R. petraeum</i> :				
Taylor.....	4	4			Gravatt.....	2	3	} XX	-----
<i>R. missouriense</i> :					Spaulding.....	1	1		
Rostrup.....	1	1	-----	-----	<i>R. petraeum atro-purpureum</i> :				
Gravatt.....	1	1	} XX	X	Gravatt.....	1	1	XX	-----
Lyman.....	1	1			<i>R. reclinatum</i> :				
Spaulding.....	1	1			Jaczewski.....	0	1	-----	-----
Taylor.....	3	3			Klebahn.....	1	1	-----	-----
<i>R. missouriense</i> X					Schøyen.....	1	1	-----	-----
<i>reclinatum</i> :					Sorauer.....	0	1	-----	-----
Gravatt.....	2	3	X	-----	Tubeuf.....	1	1	-----	-----
<i>R. montigenum</i> :									
Spaulding.....	1	1	X	-----	Gravatt.....	4	4	} X	X
<i>R. multiflorum</i> :					Hedgecock.....	1	1		
Rostrup.....	1	1	-----	-----	Spaulding.....	1	1		
Rhoads.....	0	1	} X	-----	<i>R. reclinatum grafted on R. aureum</i> :				
Spaulding.....	1	1			Klebahn.....	6	7	X	-----
<i>R. nevadense</i> :					<i>R. reclinatum</i> X				
Gravatt.....	0	1	} XX	-----	missouriense:				
Spaulding.....	2	2			Gravatt.....	2	2	XX	XX
<i>R. nigrum</i> :					<i>R. reclinatum</i> X ro-tundifolium:				
Eriksson.....	18	18			Gravatt.....	1	1	X	-----
Ewert.....	6	6			<i>R. robustum</i> :				
Hennings.....	1	1			Spaulding.....	1	2	} XX	-----
Klebahn.....	11	12			Taylor.....	2	2		
Jaczewski.....	1	1			<i>R. roezli</i> :				
McCubbin.....	3	4			Gravatt.....	0	1	} X	-----
Naumann.....	1	1			Taylor.....	1	1		
Rostrup.....	1	1			<i>R. rotundifolium</i> :				
Sorauer.....	1	1			Sorauer.....	1	1	-----	-----
Tranzschel.....	1	1							
Tubeuf.....	2	2			Gravatt.....	1	1	} XX	X
Gravatt.....	29	36			Spaulding.....	c 0	8		
Hedgecock.....	3	3			Taylor.....	c 6	6		
Marshall.....	3	3			<i>R. rubrum</i> :				
Merrill.....	5	5	} XXX	XXX	Jaczewski.....	0	1	-----	-----
Spaulding.....	8	8			Klebahn.....	1	1	-----	-----
Taylor.....	11	21			Neger.....	0	1	-----	-----
York.....	1	1			Rostrup.....	1	1	-----	-----
<i>R. nigrum</i> "aconiti-folium":					Sorauer.....	1	1	-----	-----
Spaulding.....	1	1	XX	-----					
<i>R. nigrum</i> "crispum":									
Sorauer.....	1	1	-----	-----					

b Slight.

c Part seedling plants.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, etc.—Continued.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 1.—Species of <i>Ribes</i> —Contd.					SEC. 2.—Varieties of <i>Ribes nigrum</i> .				
<i>R. rubrum</i> "petrowalskianum":					Bang up:				
Spaulding.....	0	1	X	-----	Gravatt.....	1	1	X	-----
Spaulding and Merrill.....	1	1			Beauty:				
<i>R. rubrum pubescens</i> :					Spaulding.....	1	1	XXX	-----
Spaulding.....	1	2	X	-----	Black Dutch:				
<i>R. rubrum scandicum</i> :					Gravatt and Taylor.....	5	5	XXX	-----
Merrill.....	2	2	XX	-----	"Black English":				
Rhoads.....	1	1			Colley, Gravatt, Spaulding, and Taylor.....	14	14	XX	-----
Spaulding.....	1	1			Black Grape:				
Taylor.....	1	1			Spaulding.....	1	1	X	-----
<i>R. rubrum "sibiricum"</i> :					Blacksmith:				
Spaulding and Merrill.....	2	3	X	-----	Gravatt.....	3	3	XX	-----
<i>R. sanguineum</i> :					Black Victoria:				
Neger.....	1	1	-----	-----	Gravatt, Marshall, and Spaulding.....	24	27	XX	XXX
Sorauer.....	1	1			Boskoop:				
Tubeuf.....	1	1			Colley, Spaulding, and Taylor.....	5	8	XX	XX
Gravatt.....	4	6			Carter:				
Spaulding.....	4	4	X	-----	Gravatt.....	4	4	XX	XX
Taylor.....	1	1			"Cassis à fruit noir":				
<i>R. sanguineum "albidum"</i> :					Gravatt.....	2	2	XX	XX
Gravatt.....	6	6	XX	XX	Champion:				
<i>R. sanguineum "floro pleno"</i> :					Hedgecock, Marshall and Spaulding.....	5	5	XXX	XX
Gravatt.....	1	1	X	X	Climax:				
Marshall.....	2	4			Gravatt, Marshall, Merrill, and Spaulding.....	14	14	XXX	XXX
<i>R. setosum</i> :					Clipper:				
Sorauer.....	1	1	-----	-----	Gravatt.....	2	2	XX	XX
Gravatt.....	3	4			Collins:				
Spaulding.....	1	1			Spaulding.....	1	1	X	-----
<i>R. speciosum</i> :					Coronation:				
Gravatt.....	3	7	XX	X	Gravatt and Taylor.....	3	3	XX	-----
Spaulding.....	1	1			Eagle:				
<i>R. sterilis</i> :					Gravatt and Spaulding.....	13	13	XX	XX
Spaulding.....	0	2	0	-----	Eclipse:				
<i>R. succirubrum</i> :					Spaulding.....	2	2	X	-----
Gravatt.....	1	2	XX	XX	Edina:				
Spaulding.....	0	1			Gravatt.....	4	4	XXX	-----
Taylor.....	1	1			Ethel:				
<i>R. tenue</i> :					Spaulding and Taylor.....	2	2	X	-----
Gravatt.....	1	1	XXX	-----	"French Black":				
Spaulding.....	0	1			Gravatt and Spaulding.....	4	4	XX	XX
<i>R. transbaicalis</i> :					Kerry:				
Spaulding and Merrill.....	1	1	X	-----	Gravatt.....	4	5	XX	XX
<i>R. triste</i> :					Lee:				
Spaulding.....	7	7	XX	X	Gravatt, Marshall, and Spaulding.....	14	16	XX	XXX
Taylor.....	0	1			Magnus:				
<i>R. viburnifolium</i> :					Gravatt.....	4	5	XXX	XXX
Taylor.....	5	5	X	-----	Mammoth:				
<i>R. villosum</i> :					Gravatt.....	2	2	XX	XXX
Gravatt.....	0	4	0	-----	Marvel:				
<i>R. viscosissimum</i> :					Gravatt, Spaulding, and Taylor.....	6	6	X	-----
Gravatt.....	3	3	XX	-----	Naples:				
<i>R. vulgare</i> :					Marshall and Taylor.....	4	5	XXX	XXX
Schøyen.....	1	1	XX	-----	Norton:				
Hedgecock.....	3	3			Gravatt.....	1	1	X	-----
Spaulding.....	1	1							
<i>R. vulgare macrocarpum</i> :									
Spaulding.....	1	1	X	-----					
<i>R. wolfii</i> :									
Spaulding.....	2	2	XX	-----					

b Slight.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, etc.—Continued.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 2.—Varieties of <i>Ribes nigrum</i> —Con.					SEC. 3.—Varieties of <i>Ribes vulgare</i> —Con.				
Ontario:					Everybody's:				
Gravatt.....	2	2	XX	-----	Gravatt.....	6	6	X	X
Saunders:					"Eyath Nova":				
Gravatt and					Merrill and				
Spaulding.....	6	9	XX	XXX	Spaulding.....	0	3	0	-----
Seabrook:					Fay:				
Spaulding.....	3	3	XXX	-----	Gravatt.....	1	1	X	XX
Standard:					Filler:				
Spaulding.....	1	1	X	-----	Gravatt.....	5	5	X	X
Success:					Fox Red:				
Spaulding.....	1	1	X	-----	Gravatt.....	4	4	X	X
Topsy:					Franco-German:				
Gravatt.....	2	2	XX	-----	Gravatt, Mar-				
Wales:					shall and				
Spaulding.....	1	1	XX	-----	Spaulding.....	0	21	0	bX
Winona:					Frauentdorf:				
Spaulding.....	1	2	X	-----	Gravatt.....	2	2	X	-----
Woods:					"Giant Red":				
Gravatt.....	4	4	XXX	-----	Gravatt and				
SEC. 3.—Varieties of <i>Ribes vulgare</i> .					Marshall.....	8	10	X	X
Admirable:					"Giant White":				
Spaulding and					Gravatt.....	4	4	X	X
Taylor.....	3	3	XX	-----	Goliath:				
Albert:					Spaulding and				
Gravatt and					Taylor.....	2	2	X	-----
Marshall.....	4	18	X	X	Greenfield:				
Angers:					Spaulding and				
Merrill and					Taylor.....	2	4	X	-----
Spaulding.....	3	3	X	-----	Holland:				
Bertin:					Gravatt.....	0	5	0	bX
Gravatt.....	2	2	X	-----	Imperial:				
"Blanc de Werden":					Gravatt.....	2	2	X	-----
Gravatt.....	4	4	X	-----	"Improved Cherry":				
Bonum:					Gravatt.....	6	6	X	XX
Gravatt.....	6	6	X	-----	Knight:				
Brandenburg:					Gravatt, Spaul-				
Spaulding.....	2	2	XX	-----	ding, and Tay-				
Buddins:					lor.....	5	6	XX	-----
Gravatt.....	2	2	X	-----	"Large Red":				
"Champagne White":					Spaulding and				
Spaulding.....	1	1	X	-----	Merrill.....	2	3	X	-----
Chautauqua:					"Large White":				
Gravatt and					Gravatt.....	4	5	XX	XX
Marshall.....	7	7	X	XX	London:				
Chenonceaux:					Gravatt and				
Gravatt and					Marshall.....	20	22	bX	bX
Merrill.....	5	5	X	-----	"Marvin Crystal":				
Cherry:					Rhoads.....	1	1	X	-----
Marshall.....	1	1	-----	X	Moore Ruby:				
Comet:					Gravatt, Hedg-				
Marshall.....	2	2	-----	X	cock, and Mar-				
"Commun Blanc":					shall.....	9	10	X	X
Gravatt.....	4	4	X	-----	New Red Dutch:				
Conde:					Spaulding.....	1	1	XXX	-----
Spaulding.....	1	1	X	-----	North Star:				
Concord:					Colley and Tay-				
Gravatt.....	3	5	X	-----	lor.....	0	1	0	XX
Crawford:					Norway:				
Gravatt.....	2	2	X	-----	Gravatt.....	5	5	XX	XX
Cumberland:					Palluau:				
Gravatt and					Gravatt, Spaul-				
Spaulding.....	5	5	X	0	ding and Taylor				
Dilnot:					Perfection:				
Gravatt and					Marshall.....	1	1	X	X
Taylor.....	3	3	X	-----	Raby Castle:				
Diploma:					Spaulding.....	2	2	X	-----
Gravatt.....	6	7	X	X	Red Dutch:				
Early Scarlet:					Spaulding and				
Merrill and					Taylor.....	2	2	X	X
Spaulding.....	2	2	XXX	-----	"Red English":				
					Spaulding.....	1	2	X	-----
					Red Grape:				
					Gravatt.....	3	3	X	-----

Slight.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, etc.—Continued.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 3.—Varieties of <i>Ribes vulgare</i> —Con.					SEC. 4.—Varieties of <i>Ribes reclinatum</i> .				
Redpath:					Achilles:				
Spaulding.....	0	1	0	-----	Spaulding.....	0	1	0	-----
Rivers:					Alma:				
Gravatt.....	4	4	(d)	-----	Rhoads and				
Sablons:					Taylor.....	1	3	×	-----
Spaulding and					Berkeley:				
Taylor.....	1	2	×	-----	Gravatt and				
Scotch:					Marshall.....	5	6	×	×
Gravatt, Merrill					Carmen:				
and Spaulding.	3	5	×	-----	Gravatt.....	5	5	×	×
Simcoe King:					Carrie:				
Spaulding.....	0	1	0	-----	Marshall and				
Skinner:					Taylor.....	4	5	×	×
Gravatt.....	2	2	×	×	Champion:				
Striatum:					Gravatt and				
Spaulding.....	1	1	×	-----	Taylor.....	1	2		-----
Transparent:					Chautauqua:				
Gravatt.....	10	10	×	×	Spaulding.....	1	1	×	-----
Turinoise:					Columbus:				
Gravatt and					Spaulding.....	4	4	-----	×
Taylor.....	5	5	×	-----	Cumberland:				
Utrecht:					Gravatt and				
Gravatt.....	2	2	×	0	Spaulding.....	2	3	×	-----
Verneres:					Downing:				
Gravatt and					Gravatt and				
Spaulding.....	4	4	×	-----	Spaulding.....	2	4	0	×
Versaillaise:					Duncan:				
Gravatt, Mar-					Merrill and Tay-				
shall and					lor.....	2	2	×	-----
Spaulding.....	6	7	×	×	Golden Prolific:				
Victoria:					Gravatt.....	6	11	×	×
Gravatt, Spauld-					Houghton:				
ing and Taylor	6	6	×	×	Gravatt and				
Warner:					Spaulding.....	2	12	×	×
Gravatt.....	2	2	×	-----	Industry:				
Wentworth:					Gravatt.....	2	2	×	×
Spaulding.....	1	1	×	-----	Josselyn:				
"Wentworth					Spaulding.....	0	3	0	×
White":					Keepsake:				
Gravatt.....	2	3	×	-----	Gravatt.....	4	6	×	×
"White Barle Duc":					Lancashire Lad:				
Marshall.....	0	1	-----	×	Gravatt.....	2	2	×	×
"White Branden-					Mabel:				
burg":					Spaulding.....	0	2	0	-----
Spaulding.....	0	1	0	-----	Mountain:				
White Champion:					Gravatt and				
Gravatt.....	3	3	×	-----	Spaulding.....	3	7	×	×
White Cherry:					Oregon:				
Spaulding.....	1	1	×	-----	Gravatt and				
White Dutch:					Taylor.....	2	7	×	×
Gravatt and					Pearl:				
Marshall.....	4	4	-----	×	Gravatt and				
White Gondouin:					Taylor.....	5	6	×	×
Gravatt and					Poorman:				
Marshall.....	5	5	×	×	Gravatt.....	2	3	×	×
White Grape:					Portage:				
Marshall.....	11	11	-----	×	Gravatt.....	4	4	×	×
White Imperial:					Smith:				
Gravatt, Hedg-					Marshall and				
cock and Tay-					Spaulding.....	3	3	×	×
lor.....	4	5	×	×	Transparent:				
"White Kaiser":					Gravatt and				
Spaulding.....	1	1	×	-----	Marshall.....	5	6	×	×
"White Leviathan":					Triumph:				
Gravatt and					Gravatt, Hedg-				
Merrill.....	5	5	×	-----	cock and				
White Pearl:					Spaulding.....	9	10	×	×
Spaulding.....	1	1	×	-----	Van Fleet:				
White Versailles:					Gravatt.....	2	2	×	×
Merrill and					Victoria:				
Taylor.....	1	2	0	-----	Gravatt.....	1	1	×	-----
Wilder:					White Lion:				
Spaulding.....	2	2	-----	×	Marshall.....	1	1	-----	×
Wilson:					Whitesmith:				
Marshall.....	1	1	-----	×	Gravatt.....	2	3	×	×

d Dead spots only.

Recently Thayer (159) and Bunyard (8) have published results of their studies of the cultivated red and white currants. They find these currants to be of mixed and badly confused parentage, but conclude that certain varieties sprang from each of the three species, *Ribes vulgare*, *R. rubrum*, and *R. petraeum*. Many varieties are still to be assigned to the proper species; hence, they are grouped in Table I under the name *R. vulgare*, for convenience, as it is yet impossible to assign all of them to any species.

The gooseberries are well known to be in many cases a mixture of *Ribes reclinatum* with several American species or even pure selections of American species. For convenience they are grouped under the species name, *R. reclinatum*.

Susceptibility of Ribes Species and Varieties to *Cronartium ribicola*.

Estimates of the susceptibility of the various species and varieties of *Ribes* have been made. (See Table I.) These are based on work done in the greenhouse and on results of the experiments out of doors on Block Island. These estimates have been made mostly by two persons, so that they are believed to be quite reliable and accurate by the standards chosen. The estimates for the inside experiments were made entirely independent of those out of doors. The two agree surprisingly. They are based on the results of work covering several years, but many of the species and varieties have been subjected to infection but a single year. A few species will be noted which have remained immune in our tests. But some of these species are known to have become infected elsewhere. This is true of *Ribes alpinum* which is reported to take this disease in Europe, although it is entirely resistant in North America (35, 53). *Ribes innommatum* has been well tested and took the disease only on newly developed leaves. It is a very resistant species. *Ribes sterilis*, *R. tenue* and *R. villosum* have not yet undergone satisfactory tests, so that no conclusive statement concerning them can be made.

The species of *Ribes* vary in susceptibility from the extremely susceptible *Ribes nigrum* to the very resistant *R. leptanthum*. On the former are produced the maximum number of uredinia and telia of the largest size, while on the latter the minimum number is produced and these are poorly developed. *Ribes alpinum* has been entirely immune with us, although it takes the disease in Europe.

The varieties of a cultivated species run fairly true to the species as a whole. Some real variation among varieties is believed to depend upon their mixed parentage. Many tests were necessarily made when the plants were not at the most favorable stage of development for the fungus to attack, and it is likely that further tests of aberrant varieties may bring most of them back into agreement with the species to which they belong. Of the varieties of the cultivated red currants

which have been tested, the following are nearly immune: Eyath Nova, Franco-German, Holland (see also Tubeuf, 174), London, Rivers, Simcoe King. That is, plants tested under these names have so far shown themselves resistant, but not entirely immune.

The cultivated gooseberries, varieties of *Ribes reclinatum* in some cases more or less mixed with American species of gooseberries, are resistant but occasionally will become infected.

Resistant species and varieties have been found reacting to the fungus and affecting it as follows:

- (1) Decreased number of uredinia and telia.
- (2) Above accompanied by reduction in size of uredinia and telia with lowered viability.
- (3) Small streaks and flecks of dead or dying tissue in infected leaves with uredinia and telia. (See Pl. V, fig. 1.)
- (4) Small dead spots formed early with very few or no uredinia and telia. (See Pl. V, figs. 3 and 4.)

This agrees essentially with the results of Stakman (149) with *Puccinia graminis* on resistant grains.

LIFE HISTORY OF CRONARTIUM RIBICOLA.

The Peridermium Stage on Pines.

THE INCUBATION PERIOD ON PINES.

According to European investigators, *Cronartium ribicola* has an indeterminate incubation period between infection of pine and production of æcia. This varies from about two to four years, and possibly much longer. In one of Klebahn's inoculation experiments he got pycnial drops on young white pines 11 months after the inoculation (71). In another instance, infection probably occurred in 1887, pycnia were produced in 1888, and æcia in 1889 (65). Recently Tubeuf (174) reported the results of successful inoculations on *Pinus strobus*. Inoculations were made on September 11, 1914; pycnia formed in July, 1915; they were also produced in 1916 in May and thereafter; æcia appeared in April, 1917.

In North America considerable attention has been given to this matter. McCubbin (84) first attacked it by extensive studies of naturally infected trees. He concluded that five seasons were necessary for most of nearly 1,600 infections in Ontario to develop mature æcia. He outlines the process as follows: first season, infection occurs; second season, dormant; third season, swelling of the bark; fourth season, swelling with pycnia; fifth season, mature æcia. This makes a lapse of about three years and six months between actual infection and the formation of mature æcia.

Stone (153) in 1917 studied this problem in a locality where the fungus was fruiting on white pines for the first time after infection occurred. The infection came from *Ribes cynosbati*, which in 1914 was heavily infected. The *Ribes* plants were removed in the spring

of 1915, so that infection was limited to the season of 1914. Of 40 infections found, 12 were on 1913 wood and produced æcia in May, 1917; 28 were on 1914 wood and produced æcia in May, 1917. The period of incubation for the former cases could not be more than three years and nine months. It may be that infection took place on 1-year-old wood, in which case the incubation period would be only two years and ten months, as was the case with the 28 infections on 1914 wood.

Study of infected branches which had just borne æcia for the first time was made by Posey and Gravatt in 1917 at Stratham, N. H. Their notes show that more than 99 per cent of these infections might be 3 years and 6 months old, but could be no older. In another locality, they found a number of æcia upon growth of the year 1915, making an incubation period of about 18 months.

The first successful inoculations of pines with sporidia of *Cronartium ribicola* are apparently those made by Klebahn on August 27, 1903 (71). *Ribes nigrum* leaves with telia were placed over two young trees of *Pinus strobus* and the whole covered with bell jars as long as the *Ribes* leaves remained fresh. On June 19, 1904, these trees had swollen twigs bearing juvenile leaves. Early in July, pycnial drops formed, after a lapse of 10 months. It is probable that in the normal course of events æcia would form the next May. This would make an incubation period of about 19 months.

The writer (133) in November, 1910, inoculated a number of healthy *Pinus strobus* trees in the greenhouse with teliospores. These inoculations were made on the young bark. In January, 1912, one each of those inoculated with wound and without wound of bark developed marked swelling. A little later pycnial drops formed, but snails ate them and the surrounding bark, so that the infections did not develop. Apparently it would have been a matter of but a few months when æcia would have formed. This would give an incubation period of about two years. In May, 1916, the writer (145) set out healthy *Pinus strobus* trees among some experimental *Ribes* bushes on Block Island, R. I. The *Ribes* were heavily infected the rest of the season. Telia began to form the latter part of July and were abundant by September. On May 10, 1918, several of these trees were found bearing æcia. This makes a maximum incubation period of about 21 months.

In 1917, 10 young plants of *Pinus flexilis* were set out in the experimental plat on Block Island. Nine of them have lived. In the spring of 1920 seven of them bore æcia of *Cronartium ribicola* on the growth of 1918, and the other two were much swollen and discolored, so that if alive they will certainly produce æcia in 1921. It appears that *P. flexilis* is very susceptible. The experiments on Block Island indicate that it is even more susceptible than is *P. strobus*. The incubation

period would be about 20 months. A number of *P. strobus* trees set in 1917 also bore æcia in 1920, and many more will do so in 1921.

Clinton and McCormick (12, 15) found that artificially infected trees of *Pinus strobus*, kept in the greenhouse, developed pycnial drops in five to six months after inoculation.

All of the writer's experience in various outbreaks of this parasite shows that most of the newly formed æcia are located on nodes and internodes that are 3 years old or over. It is rather exceptional for æcia to be borne on needle-bearing wood 2 years old, in which case the minimum incubation period is about 18 months. The average incubation period out of doors is approximately 3 years and 6 months.

TIME, PLACE, AND MANNER OF INFECTION OF PINES.

There is constant danger of infection of pines at any time after telia form; that is, after about the 1st of June. The teliospores produce sporidia in 6 hours under favorable conditions.⁶ The sporidia germinate immediately. According to Clinton and Miss McCormick, infection of pine leaves may take place within 48 hours (14, 15) after the germinating sporidia are placed on the leaves. Any period of moist weather of 54 hours or longer after about June 1 may cause infection of pines.

The available evidence indicates that infection of pine twigs takes place in or about the bases of the leaf fascicles (71, 84). If this is true for most cases, as seems likely, infection of *Pinus strobus* can occur only on wood that is 1 or 2, or exceptionally, 3 or 4 years old. This follows from the fact that the needles of this species ordinarily live only two seasons, but rather exceptionally they may live three or four seasons.

Tubeuf (174) in 1917 published the results of successful inoculations with sporidia of *Cronartium ribicola* on pines. He inoculated *Pinus strobus*, *P. lambertiana*, *P. excelsa*, *P. parviflora*, *P. peuce*, *P. cembroides*, *P. flexilis*, *P. montezumae*, and *P. cembra*. He got yellow spots on the needles of *P. lambertiana* but no further results were noted. *P. strobus* became infected readily and bore æcia, but none of the other species showed definite signs of infection. Infection evidently occurred in the needles, many of them having yellow spots. They were also present on the stems. Mycelium was abundant in the yellow areas. Tubeuf says that infection of the stem from the leaves is not common, but that direct infection of the stems is much more likely to occur. No pycnia were obtained on leaves, although the masses of mycelium in the yellow spots seemed to form the base for the pycnial spots in the bark. Older plants of *Pinus strobus* became infected less readily than those only 2 years old. This

⁶ York, H. H. Field studies of *Cronartium ribicola* in the White Mountains of New Hampshire. Seen in manuscript. To be published in Phytopathology.

infection of young plants he attributes to the fact that shoots bearing primary (juvenile) leaves go into the winter season with buds at all stages of growth, and many are incompletely protected by bud scales. Inoculations made on September 11, 1914, with sporidia succeeded on the primary leaves, on the secondary (mature) leaves, and on the epidermis of growing buds and of young shoots. Yellow spots were present on all these parts in the spring of 1915.

Clinton and Miss McCormick (12, 14, 15) have recently announced successful inoculations in the leaves of *Pinus strobus*. Studies of thousands of infections show that infection takes place through the stomata of the pine leaves of all ages. Inside the stoma a sub-stomatal vesicle is formed which is of a characteristic shape. Thence the mycelium extends into the vascular bundle and then grows rapidly downward to the twig. Infection may take place in 48 hours. Inoculations on stems did not succeed. Inoculations on opened and unopened buds succeeded in a few cases, results being somewhat doubtful with the unopened ones. Infections on the leaves become visible, about a month after inoculation, as tiny yellowish spots centering on the line of stomata on the under side of the leaf. These spots turn golden yellow. Similar yellow spots may form on the twig after the fungus has become established there. A yellow mottling of the infected leaves is the principal symptom of the disease at this time.

This is rarely noted in nature, but two instances having been seen by the writer before 1920 (131, 132, 133, 134). The spots were on both leaves and stems of naturally infected *Pinus strobus* trees. Richards has recently found them on naturally infected leaves. So far as known they have been mentioned previously only by Tubeuf (174); Klebahn (71), who noted them on artificially infected trees but failed to designate the point of infection; and by Pechon (105), who observed them on naturally infected trees. The writer thought the yellow spots resulted from the growth of the fungus outward from the stem into the leaves. Klebahn seems to have been of the same opinion. It is believed that this happens sometimes. In 1920 such spots were seen on pine leaves naturally infected at Temple, N. H., and at New Boston, Mass. They are abundant in certain localities. Artificial infections have resulted from inoculations into the bark of the stem by the writer (133).

Cronartium ribicola is able to grow in bark much more than 3 or 4 years old if it once gains access to the interior. Infections have been seen which were still producing æcia on bark up to 35 years of age. A common method of infection of pine trunks 20 or more years of age is by growth of the mycelium from infected small side branches (135). (Pl. II, figs. 1 and 3.) Very often a twig near the base of a large branch becomes infected. The disease then extends

downward into the large branch, and from that into the main trunk of a tree, finally girdling it and killing the entire tree. This is true of nearly all of the older trees that have been killed in North America.

TYPES OF INFECTION ON PINES.

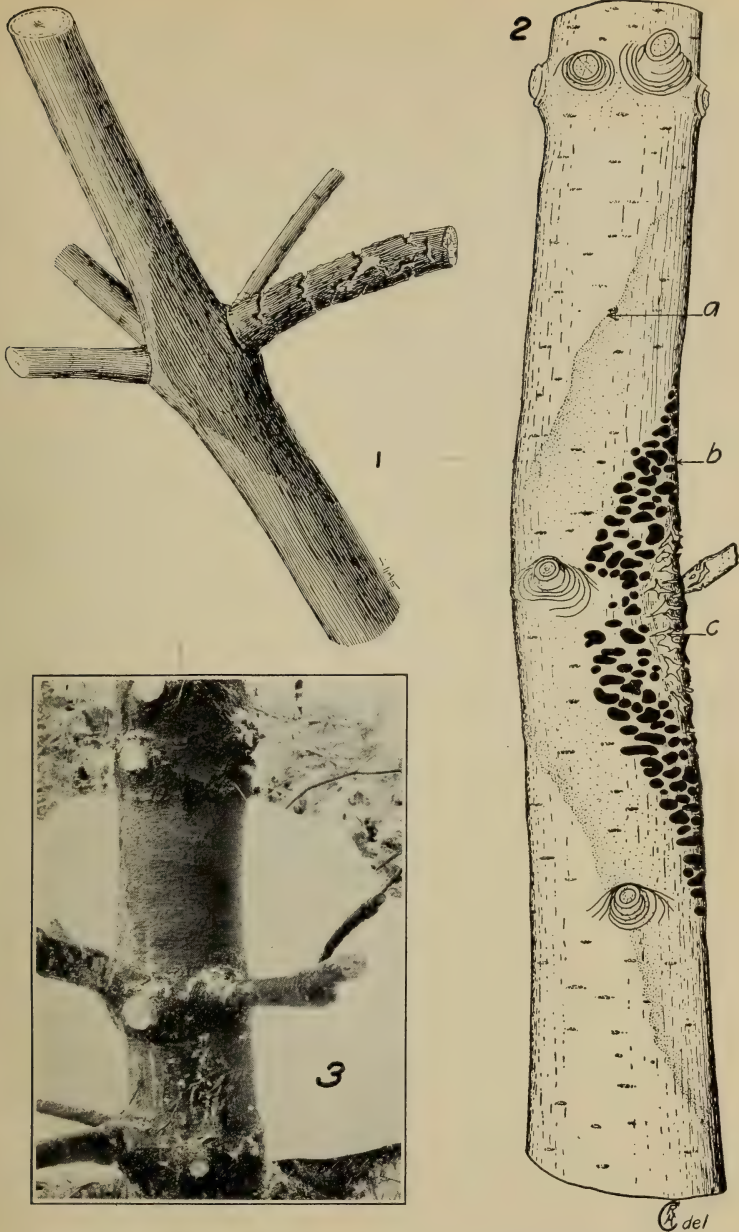
There may be said to be three types of infection on white pines resulting from natural inoculations. These are (1) direct infection of the main trunk on the leader; (2) direct infection of young branches or twigs; and (3) infection of an old trunk by spread of the mycelium from an infected branch. (Pl. II, figs. 1 and 3.) All of these are present in outbreak areas in North America. Direct infection apparently occurs only on growth not more than 3 years old. Infection of large branches or trunks, so far as we can judge, is limited only by the thickness of the bark. Old rough heavy bark of *Pinus strobus* was supposed to be immune to attack, but it has become infected by spread of the mycelium from infected side branches. It is a common method of entry of the fungus into older parts of a tree which were formerly supposed to be too old to become infected. It is very frequent in older outbreaks. This has not been mentioned in European literature until 1918 when Fischer (41) called attention to it.

DIAGNOSIS OF BLISTER RUST IN PINE BARK BY MEANS OF THE MYCELIUM.

In 1916, and to some extent before that date, when numerous specimens of diseased white pines were sent to the Office of Investigations in Forest Pathology for quick and reliable diagnosis of the blister rust, many specimens were received which bore no fruiting bodies of the parasite. The appearance of many of these made it practically certain that they were infected with *Cronartium ribicola*. Colley (16, 19) studied the problem and shortly decided that the mycelium and the haustoria did furnish reliable evidence for identifying this parasite in the bark of *Pinus strobus*. The large intercellular hyphæ, the large and abundant haustoria, and their manner of attacking the living cells, were found to be entirely different from the characters of any other known parasite of *Pinus strobus*. The use of these characters for four successive seasons with great numbers of specimens in various stages of development has indicated that such diagnosis of the disease is absolutely reliable.

LONGEVITY OF THE MYCELIUM IN PINE SLASH.

In November and December, 1916, some diseased native white pines were cut in outbreak areas in Ontario and in Maine, the slash being left lying upon the ground. Entirely independent observations made by McCubbin in Ontario and by Posey in Maine early in May, 1917, showed that new æcia were forming abundantly upon



SECTIONS OF PINE TREES, SHOWING TYPICAL PROGRESS OF BLISTER-RUST INFECTION.

FIG. 1.—Section of the trunk of a young tree of *Pinus strobus*, showing entrance of the blister rust into the trunk from an earlier infected branch. The dark shading on the trunk indicates the visibly infected portion. $\times 1$. Drawn by J. M. Shull. FIG. 2.—Trunk of young tree of *Pinus strobus*, about 2 inches in diameter, showing (by zonation) the progress of the blister rust. The disease entered the trunk from the side branch. The cracked bark (c) indicates where aecia have formed; the black spots (b) indicate the developing pycnia; the shaded part outside (a) indicates the area where the bark is discolored. $\times \frac{1}{2}$. Drawn by R. H. Colley. FIG. 3.—A trunk 8 to 10 inches in diameter. The disease attacked the swollen twig first, then ran downward to the main branch, from which it has spread into the trunk. The latter will soon be girdled and the tree will die. Photographed by J. F. Collins.

the cankers on this slash (89). This overwintering of the fungus by means of the mycelium is favored by the slash lying in moist places. It was also noted that a piece of a trunk several inches in diameter was producing new æcia after being kept in the dry air of the artificially heated laboratory in Washington about 6 weeks. These findings are significant, since they show that the cutting of diseased pines, if done in the late fall, winter, or early spring, must be accompanied by careful collection and burning of the infected slash, if infection of near-by *Ribes* is to be prevented. This difficulty may be obviated by cutting the pines in summer when the following hot, dry weather will kill the slash and end the life of the mycelium within it.

SEQUENCE OF PYCNIA AND ÆCIA AND PROGRESS OF THE DISEASE IN PINE BARK.

Study of many blister-rust cankers of varying ages in the bark of large trunks of pine has shown that the disease extends through the bark in a regular and well-defined manner. Cankers of several years' standing usually consist of four distinct zones (20) (Pl. II, fig. 2):

(1) An inner central zone of dead rough bark where æcia have been borne in preceding seasons. This area often has at its center a dead lateral branch or twig down which the disease has traveled from its first place of infection. This is the most common method by which infection of large trunks and branches takes place.

(2) An annual zone of living, swollen bark surrounding the dead area. Here is produced the latest crop of æcia. This zone varies in width from a fraction of an inch up to several inches.

(3) A zone of discolored living bark bearing the pycnial spots, drops, or scars.

(4) An outer zone of living bark, little or not at all swollen, showing a yellowing or bronzing of the normal green color of the smooth living white-pine bark. These zones of course move steadily outward with the progress of the mycelium.

This sequence of zones of activity shows that we have a regular succession of events, as follows:

(1) Invasion of healthy bark by the fungous mycelium, resulting in yellowing and bronzing of the invaded bark.

(2) Formation of pycnia in discolored and often swollen, but still living bark.

(3) Formation of æcia in living bark which has previously borne pycnia.

(4) Death of the bark which has borne æcia in abundance.

Investigations by Gravatt and Posey, and Colley (20, p. 650-651) indicate that the bark is often killed by invading secondary fungi as well as by *Cronartium ribicola* itself. Rhoads,⁷ York,⁸ and Pennington⁹ found that occasional patches of bark, where æcia have been borne the previous year, remain alive and bear a second crop of æcia the second season.

⁷ Rhoads, A. S. Studies on the rate of growth and behavior of the blister rust on white pine in 1918. Seen in manuscript. Published in *Phytopathology*, v. 10, p. 513-527. 1920.

⁸ York, H. H. Op. cit.

⁹ Pennington, L. H. Investigations on the white-pine blister rust in New York. Seen in manuscript. To be published as Tech. Bul., N. Y. State Col. Forestry.

Rhoads¹⁰ came to the conclusion that the disease spreads from the original point of infection upward and downward at about equal rates of progress. Posey and Gravatt, and Rhoads found that it spreads at nearly the same rate laterally on both sides. Progress upward and downward is usually more rapid than it is sidewise. It also appeared that in infections not yet bearing æcia, the point of greatest swelling is where infection first took place and where æcia will be first produced. Very often a dead twig or a leaf scar shows very plainly the original point of entrance of the fungus to the bark. Rhoads concluded that infections on shaded lower branches do not spread as rapidly as those on vigorously growing ones, but Posey and Gravatt¹¹ find that the former are more likely to be attacked by secondary fungi, which soon kill the branches.

Posey and Gravatt¹¹ found that there are more or less frequent instances in old infected areas of white pines where the infections on lateral branches die out. The statement (131, p. 16; 141, p. 5) that trees once infected with this fungus never recover was largely based upon studies of trunk infections. Like all rules, it has its exceptions, as here indicated. At Kittery Point, Me., Posey and Gravatt studied one of the oldest outbreaks in North America. Trees of all ages from a few years up to 50 or 75 were infected. Here it was found that secondary fungi often kill the blister rust in an infected branch and that increasing suppression of lower branches killed many of the infected ones before the blister rust spread to the trunk of the tree. It was found that about 15 per cent of all the infected trees in the area studied recovered from the disease by the action of these two factors.

THE PYCNIA AND PYCNOSPORES OF *CRONARTIUM RIBICOLA*.

The pycnosporos of the Uredinales have received comparatively little attention, since it has been generally accepted that they are apparently functionless (10, 21, 70, 110, 122, 155). The writer can find but little data upon which this idea is based. Plowright (110), Thaxter (158), Jaczewski (47), and Klebahn (68) are the only investigators known to the writer who have actually inoculated plants with the pycnosporos of their rusts. It seems that the pycnosporos should be more thoroughly tested.

The work with pycnosporos of *Cronartium ribicola* in Europe seems to be limited to that of Klebahn (68), who made inoculations with them upon young *Pinus strobus* trees without infection occurring. Even in this case there was not a clear-cut result, such as is to be desired. More recently Colley (18) has shown the importance of the pycnial spots, drops, and scars as symptoms of the blister rust in pine bark, and still more recently (20) he has investigated their morphology and cytology.

¹⁰ Rhoads, A. S. Op. cit.

¹¹ Posey, G. B., and Gravatt, G. F. Field studies on the white-pine blister rust at Kittery Point, Me. Seen in manuscript.

GERMINATION OF THE PYCNOSPORES.

Plowright states that pycnospores (spermatia) of some of the Uredinales have been germinated in sugar solutions by Cornu and himself (110). Brefeld (7) states that the spermatia of several rusts have been germinated in culture solutions. Later Carleton (10) stated that he had been able to germinate the pycnospores (spermatia) in but a single instance.

The spermatia of *Uredo caeoma-nitens* Schwein., budded sparingly on May 31, 1893, after 24 hours in a dilute solution of honey, but would not germinate in water.

Still later he said (11):

Until recent years it was not supposed that the spermatia produced regular germ tubes, but that the germination is always simply a process of budding. Dr. N. A. Cobb and the writer have shown, however, that ordinary germ tubes are produced in the germination of these spores as well as in the other spore forms * * *. Spermatia, though germinating readily in water, will be found to do much better in a rather dilute sugar solution, or perhaps still better in a solution of honey.

Investigations were made in 1918 by York and Overholts,¹² who tested their germination in water and in various solutions of glucose, cane sugar, dextrose, maltose, lactose, peptone, extract of macerated Ribes leaves, and extract of macerated pine bark. Fresh pycnospores gave no germination. Pycnospores subjected to the cold of an ordinary refrigerator from 3 to 20 days gave degrees of germination increasing with the length of time in cold up to 18 days. Germination occurred in 3, 5, and 6 per cent cane sugar and in 3, 6, and 10 per cent dextrose. The stronger dextrose solutions gave the best results. No germination occurred in tap water in any case.

SEASON OF PRODUCTION OF PYCNIAL SPOTS, DROPS, AND SCARS.

The dark spots (Pl. II, fig. 2, *b*) which precede the exudation of the pycnial drops may be found in the infected bark at all times of the year. Records and observations made from 1909 to date furnish definite data on the season of pycnial drop formation. (See Table V, p. 72.) The pycnial drops are produced immediately after the æcial season; that is, from about June 20 until winter. The rusty-brown scars left after the disappearance of the drops may be seen at all times of the year on old cankers. On new infections the scars, of course, do not appear until the drops have formed and disappeared. All of these are positive symptoms of this disease in white pines.

THE ÆCIA AND ÆCIOSPORES OF CRONARTIUM RIBICOLA.

SEASON OF PRODUCTION OF THE ÆCIA.

The æcia develop at varying dates in the same locality in different years, according to the season. The locality, whether a warm or cold exposure, at a low elevation or a high one, well to the south or

¹² York, H. H., and Overholts, L. O. The germination of the pycnospores of *Cronartium ribicola*. Seen in manuscript. To be published in *Phytopathology*.

far north, has much to do with the time that the æcia appear. They begin to push through the bark several weeks before they break open and distribute the æciospores. Open blisters have been noted as early as April 5 in eastern Massachusetts, but they were nearly three weeks later in the Adirondacks the same spring. Table V (p. 72) gives specific data so far as they are available for this and related dates.

Klebahn (68) stated that æciospores are produced by an æcium of *Cronartium ribicola* for more than 14 days. Posey and Gravatt¹³ found that æciospore production took place at Kittery Point, Me., in 1917, from April 29 to July 1.

In the spring of 1918, Rhoads made observations at Kittery Point, Me., to determine how long individual æcia produce spores.¹⁴ On May 3, he stuck pins, bearing numbered pieces of paper, into 300 æcia on various trees just as they first broke open. On May 20, the peridia of all but 63 of the æcia were entirely gone with most of the spores. On May 29 remnants of but 19 were left and on June 4, none. Therefore, in 1918 the æciospore season was about 4 weeks long at Kittery Point, Me.

York¹⁵ working at North Conway, N. H., in 1918, found that a few individual æcia contain viable spores for from 20 to about 30 days. A study of æcial production on single cankers showed that æcia matured for a period of about 30 days. These infections were all on relatively small twigs and branches. On larger branches or trunks the period may be longer. Study of the period of æcial production in that entire region showed that it was approximately 70 days. At Lewis, N. Y.,¹⁶ the æcial season in 1919 was slightly more than two months in length. After the main æcial season, late straggling æcia form. Rhoads¹⁴ noted that æcia occasionally develop on areas of bark which bore æcia the preceding year, but which were still alive.

York noted a newly formed æcium of *Cronartium ribicola* near Littleton, N. H., on July 21, 1918 (179). Several still more remarkable cases were noted by York and Ninman at Amery, Wis., on September 15 and 16, 1919. Such late æcia appear to be unknown for any of the other stem Peridermiums except *C. occidentale*, which has an æcial season from June to August. Numerous instances are known where *C. ribicola* was entirely absent on *Ribes* in a given locality early in the season, but later was found to be present in greater or less abundance. Some of these infections may originate from such late æcia. These late æciospores may remain viable over winter in the æcia, since Dosdall (29) has found that æciospores occasionally retain viability until the next spring.

¹³ Posey, G. B., and Gravatt, G. F. Op. cit.

¹⁴ Rhoads, A. S. Op. cit.

¹⁵ York, H. H. Op. cit.

¹⁶ Pennington, L. H. Op. cit.

Observations by Pennington ¹⁷ on the æcia showed that more æcia were produced per canker and many new cankers were fruiting in 1919, so that more æciospores were produced that year than in 1918 in the Adirondacks. Observations on the first generation of uredinia and the results of spore-trap work indicated, however, that not as many æciospores were set free in 1919 as in 1918. This is supposed to have been due to heavy rains, which beat them down from the air. The distribution of the first generation of uredinia showed that the æciospores were as widely disseminated in 1919 as in 1918.

DISTANCE OF DISSEMINATION OF THE ÆCIOSPORES.

As is true of many of the more difficult points in the life history of *Cronartium ribicola*, European statements concerning the distance that the æciospores are distributed are based apparently mostly on personal opinions. The value to be attached to these statements seems to rest on the known excellence, or the reverse, of the published work and judgment of the writer who is being considered. European mycologists have mentioned a number of instances where this fungus appeared on *Ribes* which were said to be far removed from white pines. But some of these cases were later found to be actually much nearer diseased white pines than was at first supposed. Tubeuf (166) has stated that the æciospores spread the disease up to 500 meters or more. On the other hand, a considerable number of definite recommendations for separation of the alternate hosts set a distance of only 30 to 100 meters (131, p. 41-42).

In North America earlier field experience indicated that the æciospores spread the disease for rather short distances from their source. It was recognized from the beginning that these spores are exceedingly light and well adapted to wind dispersal, and it was stated that our knowledge of their dispersal was very limited. Special efforts have been made for three seasons to gather more data on this problem.

Posey, in 1917, set bushes of *Ribes nigrum* in a salt marsh at Kittery Point, Me., at varying distances from infected pines before uredinia were formed. Some infection resulted from æciospores upon *Ribes* plants more than a quarter of a mile from any white-pine trees. The infecting spores probably traversed several hundred yards additional, as the nearest pines were not known to be diseased. The heavily infected area was about $1\frac{1}{4}$ miles distant, and the infecting spores may easily have come that distance.

Posey also examined the islands of the Isles of Shoals, off Portsmouth, N. H., for the presence of *Cronartium ribicola*. He found no pines, but a number of *Ribes hirtellum* plants. A few leaves were

¹⁷ Pennington, L. H. Op. cit.

found infected with the fungus. In 1920, Snell reexamined these islands much more carefully. He again found the fungus on several leaves and decided that it is evidently a case where the æciospores were blown from infected pines to the islands. The islands are about 7 miles from the mainland, so that it appears that the æciospores may be blown this distance and infect *Ribes*. There appeared to be no reason for thinking the fungus wintered over. At any rate, it must have come from the mainland originally. The islands where the disease was found are very seldom visited, so carriage of spores in this way appears to be eliminated.

McCubbin (88) found that the æciospores fall about 8 feet in seven minutes in still air. This indicates a very wide potential distribution of these spores by a moderate breeze.

In 1918, York and Overholts (cited in Spaulding, 145) worked in the White Mountains of New Hampshire in a generally infected region. Much work was done with spore traps and much time spent in examination of *Ribes* plants which were isolated from white pines. The work proved that the æciospores are distributed for miles to the tops of adjacent mountains approximately 3,000 feet high, that they arrive in a viable condition, and that they are the means by which the disease spreads far and wide to *Ribes*.

In 1918, also, Pennington and Snell (cited in Spaulding, 145) worked in the eastern Adirondack region of New York. Spore traps here gave valuable contributory evidence, but study of the distribution of the first generation of urediniospores with reference to neighboring white pines gave the best results. Here it was found that spore traps caught æciospores up to 550 feet from any pines. Within a large area of cultivated land at Essex, N. Y., an intensive study was made by Snell (128) of the first generation of urediniospores. In this area the *Ribes* were found to have first-generation uredinia sparingly and widely scattered; that is, the æciospores causing the infection evidently came from a considerable distance. In one case diseased *Ribes* were found three-fourths of a mile from any white pine. Several others were found at smaller distances from any pine trees. It was concluded that the æciospores came from a distance of not less than three-fourths of a mile and probably much farther.

These conclusions concerning the wide spread of æciospores in the two localities were arrived at independently and without the knowledge by either party of what conclusions had been reached by the other.

In 1919, Snell (128) found near Rush Lake, Minn., infections on *Ribes* leaves which were $1\frac{1}{4}$ miles from the nearest pine and about 3 miles from the nearest known diseased pine. Many such infections were found in the same general area which were half a mile or more from any pine. These infections were found developing when the first generation of uredinia appeared throughout that general in-

fected area. They must have been produced by æciospores which had been blown at least the above distances.

In 1919, York caught and germinated æciospores on the summits of two mountains nearly 4,300 feet above the adjoining lowlands. It is evident that altitudes such as this do not prevent the spread of this fungus. Pennington¹⁸ caught æciospores up to 1,200 feet distant from pines and found diseased *Ribes* three-fourths of a mile from any pine tree.

AGENTS DISSEMINATING THE ÆCIOSPORES.

It has been evident from the beginning that wind is a most efficient and active agent in the distribution of the spores of *Cronartium ribicola*. While the probability of spore carriage by other agents such as insects and the larger animals was recognized, no time could be spared for work upon it. More recently, Gravatt and Marshall (45) and Gravatt and Posey (46) have made some studies of this sort.

Gravatt and Marshall worked in the experimental greenhouse where no æcia were present. They found that pycnia and the surrounding bark tissues were eaten by sow bugs.

Gravatt and Posey (46) made studies in the field in a heavily infected pine area at Kittery Point, Me. Here it was found that gipsy-moth larvæ, which were abundant, fed eagerly on the pycnia and æcia of the blister rust and also ate the bark tissues immediately adjacent to them. It was found that in some cankers a considerable percentage of the fruiting æcia were thus destroyed. But a few ingested spores remained viable, as tests in hanging drop cells in tap water yielded a few germinations. These larvæ also were carriers of abundant æciospores on their bodies, many being of a decided yellow color from the spores with which they were dusted. The gipsy-moth larvæ are known to have been blown 20 miles or more. Within the gipsy-moth infested area these larvæ are then dangerous agents in the distant spread of the disease, a fact not previously appreciated.

Notes made by Gravatt show that a wood mouse caught in the outbreak area at Kittery Point, Me., carried a small number of æciospores on its body. While squirrels, other animals, and birds have not been examined, there can be no doubt that they are active carriers of the spores. It is known that the æciospores become attached readily to clothing, and there can be no doubt that persons may carry the disease, at least locally, in this manner.

In a number of outbreak areas where pine infections were just about to produce pycnia for the first time, it was noted by several observers¹⁹

¹⁸ Pennington, L. H. Op. cit.

¹⁹ Rhoads, A. S. Op. cit.

(143, 144) that squirrels ate the swollen bark from the infected parts of the branches. (Pl. III.) They undoubtedly run over fruiting cankers and pick up æciospores on their fur and feet. Porcupines may act in the same manner. Birds undoubtedly carry these spores to some extent, and as in the æcial season they begin nesting and largely remain in the same locality they, too, act only as local carriers.

Some indications have been noted where a road traverses a narrow valley, or a narrow clearing in a forest, that automobiles create drafts which carry spores to some distance along the highway. It seems entirely possible for steam trains and electric cars to do the same thing.

POSSIBLE AUTECISM OF THE ÆCIOSPORES.

The possible autecism of the æciospores of *Cronartium ribicola* has been considered. As early as 1913 field observations were made with this point in view, but no evidence of the spread of the fungus directly from pine to pine was found.

The question whether æciospores of other stem-inhabiting pine *Peridermiums* are capable of infecting pines has received considerable attention. In 1907 Liro (82) stated that he had made 169 inoculations of *Pinus sylvestris* with æciospores of *Peridermium pini* from the same host. No infections resulted. In 1914 Haack (48) stated that he had made similar inoculations and obtained abundant infections. His experiments were performed out of doors, with no protection from natural infection and with trees which already were naturally infected; hence, his results are worthless. In 1913 Meinecke (95) made successful inoculations with æciospores of "*Peridermium harknessii*" upon *Pinus radiata* under controlled conditions. Later (96) he changed the name of the fungus to *Peridermium cerebrum* and reported that he had successfully inoculated *Pinus radiata* with æciospores from *P. radiata* and from *P. attenuata*; and *P. muricata* with æciospores of *P. cerebrum* from *P. radiata*.

In 1915 Hedgcock (51) successfully inoculated trees of *Pinus ponderosa* var. *scopulorum*, *P. contorta*, *P. sabiniana*, *P. caribaea*, *P. mariana*, *P. pinea*, and *P. halepensis* with æciospores of "*Peridermium harknessii*" from *P. contorta*. He has also successfully inoculated *P. ponderosa* and *P. virginiana* with æciospores of "*P. harknessii*" from *P. ponderosa*.

In 1918 Klebahn (73) published the results of successful inoculations made by him with æciospores of *Peridermium pini* upon young twigs of *Pinus sylvestris*, both with and without wounds, under controlled conditions. These results throw doubt on the strict heteræcism of the æciospores of all the stem-inhabiting pine *Peridermiums*.

The following tests have been made with the æciospores of *Cronartium ribicola*: Klebahn (68, 70) repeatedly inoculated young



TRUNK AND BRANCHES OF *PINUS STROBUS*, SHOWING BARK INFECTIONS OF BLISTER RUST EATEN BY SQUIRRELS.

Photographed by W. H. Snell.

FIG. 1.—An infected branch which was evidently a young infection that had not yet formed æcia. FIG. 2.—Infected bark of living tree. Here may be seen the blister-bearing central area at the base of the branches in place, while the outer, surrounding, pycnial zone has been eaten away. FIG. 3.—Infected bark of living tree. The eaten parts were where pycnia were forming.



LEAVES OF RIBES INFECTED WITH CRONARTIUM RIBICOLA, SHOWING DIFFERENT TYPES OF ATTACK.

FIG. 1.—Lower surface of a leaf of *Ribes aureum* infected by *Cronartium ribicola*. Note the characteristic isolated infected areas, with the abundant uredinia closely crowded together. FIG. 2.—A *Ribes* bud with a single leaf which bears normal uredinia. This leaf is relatively old, being stunted in growth by adverse conditions which have held it stationary for several weeks. FIG. 3.—Lower surface of an infected leaf of *Ribes vulgare*, horticultural variety White Transparent. Note the large infected areas merging into a single one. The uredinia are not so closely crowded together as in figure 1. FIG. 4.—Lower surface of an infected leaf of *Ribes nigrum*. Note the general distribution of the telia, their grouping closely together, and their vigor of growth.

Pinus strobus trees with æciospores, but without producing infection. Hennings (53) inoculated *P. strobus* trees with æciospores and also with teliospores. No infection resulted from either. In the spring of 1916 the writer made 100 inoculations with wounds into the bark of *Pinus strobus* trees, out of doors, with fresh æciospores of *Cronartium ribicola*. No infections have resulted to date. In May, 1917, the writer (146) inoculated white pines by dipping the tips of young twigs in water containing great quantities of newly formed æciospores of *C. ribicola*. The needles as well as the twigs were covered with spores. Glassine bags, containing wet wads of cotton, were then tied over the inoculated twigs to keep up the humidity of the air. No evidence of infection is yet visible.

GERMINATION OF THE ÆCIOSPORES.

Experience shows that fresh æciospores taken from æcia just as they are about to break open, or just at the time of breaking, possess maximum infective power. Doran (28) confirms this opinion. Inoculations made with such spores are sure of results if conditions are at all favorable. Older æciospores are erratic in germination, but some of them retain viability to a marked degree. Cooling on ice stimulates their germination to a decided degree, as is shown by experiments performed by Eriksson (32), Gravatt, and others. Each spore produces from one to five (20, 29) germ tubes, which branch freely. The viability of fresh æciospores is generally high, as many as 95 per cent germinating under favorable conditions. They require 8 to 10 hours to germinate (28).

Doran (28) determined the minimum, optimum, and maximum temperatures for the æciospores of *Cronartium ribicola*. Five series of tests were made. It was found that germination in distilled-water drop cultures occurred through a range of 12° C., but the percentage of germination dropped rapidly both above and below the optimum. The minimum temperature for the æciospores was 5° C., the optimum was 12° C., and the maximum was 19° C.

LONGEVITY OF THE ÆCIOSPORES.

Klebahn (70, p. 26) seems to have been the only European investigator who has tested the longevity of æciospores. He found them strongly viable after seven weeks.

From the beginning of the work of the writer on *Cronartium ribicola* it has been known that the æciospores retain their viability for a relatively long time under favorable conditions. In 1910 a single æciospore which had been kept in the laboratory for more than five months in an open æcium on a diseased young tree which was dried and kept as a specimen germinated in water (131, p. 30). In 1915 McCubbin (85) collected on May 6 a diseased young white

pine bearing æcia. It was placed in a box in the laboratory and allowed to dry out. Tests were made by inoculating leaves of *Ribes nigrum* plants on May 7, May 21, June 4, and June 23. On the last date no infection occurred. In 1916, McCubbin repeated these experiments and found that the æciospores remained capable of infection under the conditions of his experiment at least 39 days. He believes they may retain viability considerably longer, as his tests were conducted under adverse conditions.

Æciospores collected on April 9, 1917, and kept in a closed glass vial were tested by Gravatt weekly in hanging drops of distilled water. They gave good germination for about one month, then weakened until June 9, when the last germination occurred. The tests continued until July 14. On May 7, 1917, another series of similar tests was started by Gravatt and Taylor. (See Table II.) The æciospores were placed in two glass vials with cheesecloth tied over the tops. One vial (B) was kept out of doors on a window sill on the north side of a building where the sun did not shine. The other vial (A) was kept in a dark refrigerator. The spores were tested weekly in distilled water. In most cases the cultures were placed in an ice box for about 12 hours. The spores kept in the ice box retained their color throughout, while those on the window sill had faded perceptibly by June 16. Lot A varied in germination from 8 per cent at first to 3 per cent on June 2. Germination persisted until July 2, when the last occurred in this lot. Lot B germinated freely until May 26 and not at all after June 23. Cooling and darkness in this case decidedly stimulated germination for one month and prolonged viability about 10 days after the uncooled æciospores which were exposed to light had lost all viability.

TABLE II.—*Longevity of the spores of Cronartium ribicola.*

Date, 1917.	Germination (per cent).						Notes.
	Lot A, vial in refrigerator.			Lot B, vial out of doors.			
	Æcio- spores.	Uredi- nio- spores.	Telio- spores.	Æcio- spores.	Uredi- nio- spores.	Telio- spores.	
May 8.	8	13	90	8	8	85	Not cooled in refrigerator before germination. Do. Lot A somewhat faded. Lot A much faded. Teliospores in lot A mouldy. Æciospores and urediniospores mouldy in lot A, color of lot B still fairly good.
May 12.	8	10	85	1	10	90	
May 19.	5	60	80	2	40	85	
May 26.	4	45	70	3	37	50	
June 2.	3	6	40	.8	.8	10	
June 9.	1	.65	51.3	.1	1.5	4.4	
June 16.	.1	1.35	4.5	0	0	0	
June 23.	0	0	3.5	.05	0	0	
July 2.	.05	0	.5	0	.1	-----	
July 7.	0	0	0	0	0	-----	
July 14.	0	0	0	0	0	-----	

In April, 1918, Dosdall tested in distilled water (in hanging-drop cultures) the viability of æciospores produced in 1917 (29). On April 19, 1918, a dead white-pine branch bearing a canker which had fruited in 1917 was collected at Rush Lake, Minn. While new æcia were just beginning to break open on other cankers at this time, the spores tested were not new ones, as they were dug from the bottoms of 1917 cavities after scraping off the outer exposed spores. Nor could there have been new æcia pushing up beneath the old ones, as the branch was dead. It was found that from 1 to 2 per cent of the spores germinated in distilled water, each spore producing from 3 to 5 germ tubes. It is barely possible that these spores were from an abnormally late æcium (179) and therefore were not so old as Dosdall supposed them to be. Even so, they must have been approximately 6 months old.

This experiment of Dosdall has been repeated. A dead branch bearing æcia of 1918 was collected at Kittery Point, Me., on February 25, 1919, and taken to Washington, D. C. Taylor tested the æciospores by hanging-drop cultures in tap water, but no germination of the spores could be demonstrated. Spores of other fungi were present and did germinate.

York²⁰ collected a specimen of diseased white pine bearing newly formed æcia on April 30, 1918. This was put in a paper bag and left in the laboratory away from direct sunlight until October 5, 1918. He then broke open a still unbroken æcium which had not pushed through the outer bark and made cultures of the spores. He got some germination in tap water under these condition 157 days after collection of the material. The spores were still yellow when the test was made. Spores from æcia which had broken open did not germinate.

During the season of 1918, Pennington²¹ found that in the Adirondacks the æciospores remained viable for at least four weeks after being removed from the æcia and stored in a dry place. The same season, York found that in the White Mountains æciospores from blisters in cankers cut from the tree and kept in the shade out of doors remained viable for 75 days, as shown by tap-water cultures and inoculations on Ribes leaves.

In 1919, Pennington²¹ found that æciospores, whether brought into the laboratory or left in the field soon lost their viability, less than 1 in 400 germinating after three weeks from the breaking open of the æcium producing them. Tests upon the viability of æciospores after they had been exposed to direct sunlight showed a decrease of 50 to 75 per cent in viability after three hours' exposure. After an exposure of eight hours, some of the æciospores (1 in 1,500 or 2,000) were still viable.

²⁰ York, H. H. Op. cit.

²¹ Pennington, L. H. Op. cit.

Doran (28), in 1919, found that the æciospores germinate well in distilled-water drop cultures for four weeks, when germination weakens. Germination ceased after six weeks. He does not give details of the conditions of storage of the spores.

Pennington ²² compared the number of æciospores caught in spore traps with the number of infections on *Ribes* leaves and estimated that under the most favorable conditions 1 spore in every 25 which lodged upon a *Ribes* leaf produced infection there. An estimate for the season showed that not more than 1 in 100 produced infection.

The Cronartium Stage on Ribes.

THE INCUBATION PERIOD ON RIBES.

The length of the incubation period between infection of *Ribes* by æciospores and urediniospores of *Cronartium ribicola* and the production of mature uredinia or telia varies greatly, according to the external conditions of temperature and moisture and the age and condition of the leaves infected. Examination of the records of 493 inoculation tests made in the greenhouse show that the shortest incubation period between infection and formation of mature uredinia is practically 7 days. These records show that 2.4 per cent of the cases fruited in 7 days, a like number in 8 days, 7.3 per cent in 9 days, 10.4 per cent in 10 days, 20.8 per cent in 11 days, and 19.7 per cent in 12 days. The percentage rapidly drops after this to 9.7 per cent in 13 days, 8.1 per cent in 14 days, 8.5 per cent in 15 days, 8.1 per cent in 16 days, and 3.2 per cent in 17 days.

Pennington ²² found that the incubation period on *Ribes* in the eastern Adirondack region with both æciospores and urediniospores was 11 to 18 days; it was usually 13 to 15 in mature leaves and somewhat longer in leaves which were very young when inoculated.

There are times when the fungus produces only uredinia in the greenhouse as well as in the fields. The behavior of the fungus is not entirely controlled by weather conditions, but is greatly influenced by the condition of the host leaves. At other times the fungus will produce nothing but telia. At such times telia are produced in a very short time after infection. Telia have been obtained in 9 or 10 days after infection. From 12 days upward they may be formed at almost any time up to 2 or 3 months after infection.

York ²³ in many cases has obtained telia directly from æciospore as well as urediniospore inoculations upon overmature ²⁴ leaves.

²² Pennington, L. H. Op. cit.

²³ York, H. H. Op. cit.

²⁴ The term "overmature" is here used to denote that stage of development of *Ribes* leaves where they have become tough, leathery in texture, and of maximum thickness, but have not begun to decline in photosynthetic activity.

METHODS OF INOCULATING RIBES.

The methods of inoculating *Ribes* plants are not claimed to be original with the writer or his associates. It is well known that some of these methods have been in use for many years. They are given here to show the conditions under which the experimental work was done, as follows:

(1) When plenty of spore material is available, as is usually the case with *æcio*-spores, the spores may be placed in a considerable quantity of water and the top or branch of the *Ribes* plant dipped into it. The spores will be distributed quite evenly over all parts of the dipped plant. (See Clinton (12).) This method was used by the writer as early as 1909, and has been very successful. It uses up large quantities of inoculum, however.

(2) Another method which has been much used is to spray water from an atomizer upon the part to be inoculated, then shake the dry spores upon the wet surface. This also requires a plentiful supply of inoculum. It has been a favorite method, as it gives good results with reasonable certainty.

(3) When inoculating with urediniospores from fresh leaves, the part to be inoculated is sprayed, and the leaf bearing the inoculum is turned with its lower surface on that of the healthy leaf and the two rubbed lightly together.

(4) If the inoculum is scanty, the spores are moistened with a drop of water and lightly scraped off upon the moistened healthy leaf with a sterilized scalpel or knife blade.

(5) If the inoculum is in moderate quantity, the spores are placed in a small quantity of water in a sterilized atomizer and sprayed upon the healthy plant.

(6) The spores, if fairly plentiful, are sometimes collected in a watch glass, a small quantity of water added, and then a clean camel's-hair brush is dipped into the mixture and brushed over the surface to be inoculated. With this method it is advisable to wet the inoculated part with an atomizer after inoculation, or results will be meager.

(7) Occasionally healthy leaves have been rubbed or dipped in the spore mixture described in paragraph 6.

Gravatt made comparative tests of some of the foregoing methods of applying the inoculum. This comparison showed one-fourth more infection with method 5 than with method 6, with three different species of *Ribes*. General experience has shown the order of efficiency of the methods to be as follows: 1, 5, 2, 6, 3, 7, 4. This is probably largely due to the greater number of spores used by the more successful methods. All will give good results when the relative number of spores used is considered.

With all these different methods of applying spores and moisture, it is essential to supply all the water possible without having it form large drops and run off.

As a supplement to the local moistening, it is necessary to keep the inoculated plant in a moist chamber for 12 to 24 hours. In the experiments by the writer and his associates the preferred method has been to keep the plant in the moist chamber 48 hours.

The matter of a proper moist chamber is a problem of considerable moment. Glass bell jars are good, but costly and easily broken. A tightly closed wooden and glass chamber of considerable size was

tried, but is unsatisfactory because the tender leaves of the inoculated plants are liable to scald in hot weather. Hunt (57) tested a form of the iceless refrigerator for this purpose. This is a modification of the field moist chamber described by Keitt (61, p. 540-541), without a continuous water spray. It is essentially a framework large enough to receive several potted plants, on top of which a large pan of water is placed. Around the framework is fitted a loose curtain of heavy cheesecloth completely surrounding the framework on the sides and extending from the water in the pan on top to the ground. In use, the cloth is wet thoroughly and the water in the pan keeps it wet. This keeps the air within the chamber saturated with moisture and cool, which is the desired condition for the plant. This has been very successful even in the hottest summer weather and has the desirable qualities of durability, cheapness, portability, and simplicity.

Clinton (12) has recently reported the successful inoculation of plucked leaves of *Ribes* in moist chambers. This is an old method with the rusts, and was used by Barclay in India as early as 1887 (4). Clinton has apparently developed this method to a point of maximum efficiency. It has not been used in the investigations by the writer and his associates, the preferred method being to retain natural conditions as far as possible in making susceptibility tests.

FACTORS CONTROLLING THE INFECTION OF RIBES.

Among the factors controlling infection of *Ribes* by *Cronartium ribicola* may be mentioned moisture, sunlight, age of leaves inoculated, and age of inoculum.

Frequent allusions are made by investigators to the need for abundant moisture in producing the infection of *Ribes* by æciospores and urediniospores of *Cronartium ribicola* and in spreading the fungus on *Ribes*.

In 1904, Aderhold (1) performed a series of experiments to determine the influence of moisture upon the infection of *Ribes vulgare* by æciospores of *Cronartium ribicola*. He had two inclosed cells, the air in one of which was moistened by artificial rain, while in the other it was kept relatively dry; he had similarly arranged plats open to the free air. The conditions in these cells and plats he summarized, as in Table III.

TABLE III.—Conditions in cells and plats of Aderhold's experiments.

Experiment.	Air.	Temperature.	Moisture.	Amount of light.
1. Rain cell.....	Motionless.....	High.....	Very great.....	Small.
2. Dry cell.....	do.....	Very high.....	Slight.....	Do.
3. Open rain plat.....	Moving.....	Below normal.....	Great.....	Great.
4. Open dry plat.....	do.....	Normal.....	Normal.....	Do.

Aderhold placed his experimental plants in these cells and plats on April 16. On May 6 all of the plants were heavily dusted with æciospores, and half of those in each cell and plat were put under conditions opposite to those they were in before inoculation. The plants from the closed rain cell when inoculated and replaced in the same cell took the disease heavily. Those from the closed dry cell when inoculated and placed in the closed rain cell also took the disease heavily. Those transferred from both the rain and dry cells to the dry after inoculation showed no infection. All the plants kept in the open plats failed to take the disease. It is apparent from his results that infection depends upon an atmosphere that is nearly saturated with moisture.

Experience in the greenhouse has shown that it is necessary to have abundant moisture on the leaf surface for infection to succeed. The leaf itself must be wet, without having large drops of water collect. This moisture must be retained for some time by keeping the surrounding air saturated with water vapor. Gravatt made a series of parallel tests, part of the inoculated plants being kept under bell jars 2 hours, part of them 7 hours, and another part 24 hours. Infection occurred with the 7-hour and the 24-hour plants, but not with the 2-hour tests. The writer made a series of inoculations in the greenhouse with æciospores without putting the plants in moist chambers. Not one infection resulted within 14 days, the usual time necessary to reach full fruiting condition. The plants were then put into moist chambers for 48 hours, and fair infection resulted from the spores put on the leaves 14 days before. Ewert (37) performed a similar experiment in 1912 with the same results, as did Werth (177) in 1915 and York²⁵ in 1919. McCubbin in 1916 inoculated two leaves on each of seven shoots of a *Ribes nigrum* plant. Two of the shoots were put in a moist chamber for 48 hours. The remaining five shoots were left uncovered. The leaves of only the two inclosed shoots developed infection.

It is equally necessary to have plentiful moisture for infection to occur out of doors. Hennings (53) found a severe outbreak of the disease on *Ribes* during a dry time in the Dahlem Botanical Garden, but he attributes the intensity of the attack to the daily watering (sprinkling) of the bushes. Ewert (35) says, "In the summer of 1902, moisture, the important factor for infection, was not lacking, so all conditions were favorable for the spread of the *Cronartium*." Schellenberg (123) attempted to inoculate *Ribes* bushes with æciospores from *Pinus cembra* in the open air. He attributes his failure to produce infections to the bright sunny weather prevailing at the time. In 1910, the writer (131) inoculated *Ribes* leaves with fresh

²⁵ York, H. H. Op. cit.

aeciospores out of doors. The leaves were not wet, but there was dew every night. No infection resulted.

In 1913, Stewart and Rankin (151) made some observations on this problem. On May 14 two white-pine trees were found bearing abundant open æcia. On May 17, they were cut down and burned. About 120 feet from the pines there was a small plantation of *Ribes nigrum* and *R. vulgare*. The weather was dry and unfavorable for infection of the currants to take place for several days before May 15. The forenoon of May 15 was damp, but in the afternoon it dried off and remained dry until after the trees were destroyed. They concluded that the infection of *Ribes* which developed on June 10 apparently could have taken place only in the wet forenoon of May 15. It appears to the writer that the long incubation period indicates that the spores from the pines stuck to the *Ribes* leaves without germinating until a later rainy period long enough for infection to occur.

Studies made by Pennington²⁶ and Snell (145) in New York in 1918 on *Ribes rotundifolium* show the absolute dependence of the spread of this fungus upon moist weather. They found that six distinct generations of urediniospores were produced during the season, with a slight seventh one the last of the summer. These appeared approximately two weeks after spells of rainy weather. York working in the White Mountain region for three years has made a great many successful field inoculations on various species of *Ribes* without using any form of moist chamber. His work was largely carried on, however, in localities naturally moist.

Temperature also is an important factor. Probably much of the efficiency of Hunt's iceless refrigerator inoculating chamber is due to the rather low temperature obtained. *Cronartium ribicola* is favored by low temperatures, as is shown by the optimum temperatures determined for it by Doran (28). Doran also inoculated plants of *Ribes* which were then kept at 3°, 12°, and about 22° C. No infection occurred on the first and last, while the one at 12° C. developed uredinia.

Sunshine is an important factor, indirectly if not directly. Its direct influence upon the spores is destructive (30, 88) but it is doubtful if this action is powerful enough to hinder germination greatly if sufficient moisture is present. Indirectly sunshine affects infection by quickly reducing moisture. It seems that a moderately cool temperature is most favorable and that bright sunlight may elevate the temperature above the optimum for the fungus.

The size of the leaves alone seems to have little or no influence upon their susceptibility to infection (147). Leaves as small as

²⁶ Pennington, L. H. Op. cit.

4 mm. wide have been found bearing groups of uredinia (Pl. IV, fig. 2).

The age and relative maturity of the leaf has much to do with its susceptibility. It has been the general experience that *Ribes* leaves may be overmature and also may be too young to take the disease. Infection does not occur on the leaves of a given species of *Ribes* until they have reached a certain degree of maturity. Leaves produced by buds developing in late summer or fall, even if very small, readily become infected. The different species of *Ribes* vary much in this regard. *Ribes nigrum* shows a great range in its age of susceptibility, while resistant species become infected only on leaves of a certain maturity. The most favorable stage of growth seems to be about when the leaf attains full size but has not become hardened and leathery as it does later. Tests were made by Gravatt in 1915 in the greenhouse on *Ribes nigrum*. The plant had three shoots of nearly equal size and development. They bore fully mature leaves at the base and had leaves at the tips about half grown. In this case all the leaves became infected except the lower three or four on each shoot. In 1916, McCubbin (ms. report) made several series of inoculations with aeciospores upon *Ribes nigrum* leaves of various ages. The plants were not kept under the best growing conditions, so the results are less pronounced than might otherwise be expected. He produced no infection on the youngest leaves. The older ones took the disease, but the overmature ones took it least of all. York²⁷ made greenhouse tests with plants of *Ribes nigrum*, *R. triste*, *R. glandulosum*, *R. hirtellum*, and *R. lacustre*. Leaves of various ages were present on all the plants. The mature ones showed infection first. The degree of infection was heaviest on the first species and decreased in the order named, *R. lacustre* having but two pustules on a single leaf. Later, the half-mature leaves of *R. nigrum* and the leaves of *R. triste* and *R. glandulosum* two-thirds mature became infected. The younger leaves did not become infected then, but when reinoculated later they took the disease, except that those of *R. lacustre* remained healthy. In most inoculation tests made by the writer and his associates in the greenhouse both the oldest and the youngest leaves remained free from disease, although they were treated exactly like the others. York²⁷ tested this point extensively in the open in 1918 and found that leaves just unfolding were almost invariably immune to the fungus; older ones took the disease readily; and overmature ones (especially late in the season) were immune. Pennington²⁸ reached similar conclusions working independently.

²⁷ York, H. H. Op. cit.

²⁸ Pennington, L. H. Op. cit.

Snell ²⁹ made inoculations out of doors with spores from unopened æcia on April 30, 1918. He inoculated opening buds of *Ribes glandulosum* by carefully inserting a knife so as not to injure the leaflets and inserting the spores between the folds of the leaves. The largest leaves were 3 cm. broad, the smallest 3 to 5 mm. long. It was very rainy, so there was plenty of moisture. No infection was visible on May 15, but on May 22 heavy infection was present on all the leaves inoculated. The leaves on this date ranged from nearly full size to those just opening. The infection was heaviest on the largest leaves inoculated and decreased to a light infection on the smallest. The check plants were healthy. There are two possible factors which might have delayed the infection a week longer than usual. These are cool temperature and the immaturity of the leaves. The experience of the writer leads to the belief that the latter was the principal factor involved in this case. Later Snell found natural infection on leaves of *Ribes vulgare* that were only 12 mm. wide.

It has been noted repeatedly that the earliest infections on *Ribes* leaves in the spring are about a month later than the time when the first æciospores are set free. It is a question whether this is due to very cool nights or to the immaturity of the *Ribes* leaves at this time. Noninfection of immature leaves in the greenhouse leads the writer to suspect that the latter is the main factor involved. European writers (63, 101) have stated that *Cronartium ribicola* is decidedly earlier than the native pine-stem *Peridermiums*.

Observations made by Gravatt at Block Island show that new infection in midsummer was present upon the fifth to the eighth leaves from the tip, not counting those less than 5 mm. wide; that is, on leaves just mature but not hardened.

Gravatt and York and Overholts made many inoculations of leaves, petioles, and stems with wounds, but found no evidence that infection was favored by wounds.

Whether viability of spores of *Cronartium ribicola* in culture solutions, water, etc., is a reliable index of their infective power (43) is a question which has arisen more or less insistently since inoculation experiments began. Klebahn (70) made a definite test with reference to this question with æciospores of *Cronartium ribicola*. The spores were collected on March 20 and kept dry until May 8 when the test was made. Some were sown on the leaves of *Ribes aureum*, some were sown on a cover glass coated with a thin layer of sterile *Ribes*-decoction agar, and others were sown on a cover glass moistened with water. The cover glasses were kept in a moist chamber to prevent drying. The *Ribes* plants became infected after 12 days on every leaf inoculated. The spores on *Ribes*-decoction agar germinated

²⁹ Snell, W. H. Period of exposure and size of *Ribes* leaves infected by the blister-rust fungus. Seen in manuscript. To be published in *Phytopathology*.

slowly at first, but later developed strong germ tubes in considerable quantity. Scarcely a spore in water germinated. As a result of his extensive experience with the rusts, Klebahn says:

... in other words, I believe it possible for spores which do not germinate in water to infect leaves of the host plant, and it seems to me to be expedient to distinguish between "infection power" and "viability" of spores more sharply than is ordinarily done.

Gravatt had experiences somewhat similar to the above in his inoculations with urediniospores of *Cronartium ribicola* in 1917. So pronounced has been our general experience in this regard, that many germination and longevity culture tests made in 1918 and 1919 were duplicated by check inoculations on favorable hosts so far as possible.

LOCATION OF THE INFECTIONS ON RIBES PLANTS.

SORI ON THE LEAVES.

The usual place for uredinia and telia of *Cronartium ribicola* to form is on the lower side of the Ribes leaf blade. It is rather exceptional for them to appear elsewhere. Nevertheless, they are occasionally found on the upper side of the leaf blade. They have been noted there by Gravatt in the greenhouse and by several out-of-door workers on Block Island. The following species have been seen with uredinia or telia on the upper leaf surface: *Ribes alpestre*, *R. aureum*, *R. cereum*, *R. fasciculatum*, *R. fontenayense*, *R. hirtellum*, *R. odoratum*, and also the horticultural varieties *R. aureum* var. Utah Yellow and *R. vulgare* var. White Imperial. It must not be concluded that because fruiting bodies are found on the upper surface of leaves that the infection took place there. On the contrary, in every case seen, it was very evident that the fungus had attacked the infected leaf beneath, and the attack had been so intensive that some sori were pushed through to the upper surface. There never were as many sori on the upper surface as there were on the lower one, nor were they so old.

Some inoculations have been made in Europe to determine if infection may take place on the upper surface of Ribes leaves. So far as known to the writer they are here summarized:

In 1913 Ewert (37) brought four potted plants of *Ribes nigrum* into the greenhouse. On April 10 he inoculated the leaves of one branch of plant 1 on the lower surface only with fresh aeciospores. The plant was inclosed in a glass cylinder as a moist chamber. Another branch was used as a check. On April 28 the inoculated branch bore uredinia upon 11 leaves. On April 15 he inoculated the leaves of a third branch, but did not inclose it in a moist chamber. On April 26 there was no sign of infection, and it was then inclosed in a moist chamber. On May 20 all the inoculated leaves bore uredinia. The control remained healthy.

Plant 2 was treated exactly like plant 1 except that the inoculations were made on the upper sides of the leaves. No infection resulted.

Plant 3, on April 10 and 15, was inoculated on one branch on only the lower surfaces of the leaves. Another branch was inoculated on the upper surfaces only. A third branch was left as a check. Weak infection resulted on the first branch. A repetition on April 29 with fresh *aeciospores* gave better results.

Plant 4, left untreated, was in another inclosure of the greenhouse. It remained healthy, showing that infection had not occurred before the plants were brought into the house.

On May 26 similar inoculations were made by Ewert with *uredinio-spores* on the upper sides and lower sides of leaves. Infection resulted in the latter case and also a slight infection of the lower surface of one leaf which was inoculated on the upper surface.

Another similar series of inoculations made by Ewert on June 6 gave infection only on the leaves inoculated on the lower side. He fails to say in all cases that the sori formed only on the lower surface of the leaves, but his language implies that this is the case. Attacking the problem in another way, Ewert (37) sprayed *Ribes nigrum*, *R. aureum*, and *R. rubrum*, leaves, part on the lower side only, part on the upper side only, and part on both sides, while controls were left unsprayed. The details are presented on pages 77 to 79. Because some leaves which were sprayed on the upper side developed a few sori beneath, he appears to be a little doubtful whether infection may occur on the upper surface, but he concludes that it "apparently almost exclusively takes place on the lower surface of the leaf."

The writer and his associates have made hundreds of inoculations on the upper surface of leaves of many species and varieties of *Ribes*, without a single direct infection occurring there. Numerous instances have been noted in these experiments in which infection appeared on the lower surfaces of leaves that had been inoculated on the upper side. This is believed to be due to spores reaching the lower surface in some unknown way. In fact it is very difficult if not impossible to guard against this. York and Overholts inoculated leaves of *Ribes glandulosum* on the upper side, both with and without ring cells, to prevent the spores reaching the lower surface. Slight infection occurred on the lower side in some cases where cells were not used. Where the cells were used no infection occurred. These tests were made on leaves of different ages on plants of various ages, from young seedlings up to fruiting bushes. Tubeuf (173) inoculated leaves of *Ribes nigrum* on the upper side by applying the spores in water with a brush. All of the leaves thus inoculated remained healthy except a single one which had a *uredinium* on the lower surface. He was uncertain whether a spore infected it through the lower surface or through a lesion on the upper surface.

SORI ON COTYLEDONS.

The cotyledons of young *Ribes* seedlings are apparently quite susceptible to infection by æciospores and urediniospores of *Cronartium ribicola*. Relatively heavy infection has resulted from inoculations on the lower surface of cotyledons of *Ribes americanum*, *R. missouriense*, *R. oxyacanthoides*, *R. rotundifolium*, *R. glandulosum*, and *R. fasciculatum* seedlings in the greenhouse and on *R. glandulosum* in the field.

SORI ON FLORAL BRACTS AND BUD SCALES.

Infection was secured by Gravatt from inoculations of the floral bracts of *Ribes aureum* in several different cases in the greenhouse.

Infection of opening buds and of bud scales merits more investigation. McCubbin (85) suggested the possibility of infection of partially open buds in the fall and the overwintering of the fungus, but he could not prove that it occurs. Infection of young leaves scarcely out of the bud occurs, but it seems to be limited to leaves that are relatively mature, though small. (See discussion on pp. 44 to 46.) Search for infections of buds on heavily infected *Ribes nigrum* bushes failed to reveal any infections (151, p. 44). Gravatt made inoculations of buds about to open, but with no success. York³⁰ has inoculated successfully an inner bud scale of *Ribes nigrum*.

SORI ON PETIOLES.

Next in frequency to infection of the lower surface of the leaf blade is infection of petioles. The first published account of this, so far as the writer knows, was given in 1912 (133, 134, 135) and 1913. At that time it was considered to be very uncommon. Since then a considerable number of such cases have been noted both in the greenhouse and out of doors. The following species have developed uredinia or telia, or both, upon petioles, as many as 25 or more petioles on a single plant being thus attacked: *Ribes americanum*, *R. aureum*, *R. bracteosum*, *R. cereum*, *R. culverwellii*, *R. cynosbati*, *R. divaricatum*, *R. erythrocarpum*, *R. fasciculatum*, *R. giraldii*, *R. glandulosum*, *R. inerme*, *R. lacustre*, *R. nevadense*, *R. nigrum*, *R. parishii*, *R. petraeum*, *R. robustum*, *R. setosum*. The following cultivated varieties have had petiolar attacks: *Ribes nigrum* hort. vars. Black Victoria, Climax, and Seabrook Black; *R. reclinatum* hort. vars. Berkeley, Golden Prolific, Poorman, Transparent, and Van Fleet; *R. vulgare* hort. var. White Imperial. Some 10 or 12 as yet unidentified species collected by Beattie in the Rocky Mountain and Pacific coast regions have exhibited the same phenomenon.

³⁰ York, H. H. Op. cit.

In many cases the petiole became diseased by growth of the mycelium downward from the leaf blade into it, but direct infection of the petiole occurs occasionally. This is shown by the presence of infections on the petiole one-half inch or more distant from other infections. Microscopic examination by Colley in such instances has shown the intervening tissues to be entirely free from migrating mycelium. York ³¹ had several instances where infection took place well down on the petiole, and no other infection was present either on that petiole or the leaf blade. While many inoculations of petioles have been made by members of the Office of Investigations in Forest Pathology, but few have been successful, as above indicated.

SORI ON STEMS.

Evidence of infection of *Ribes* stems has long been sought. In 1917, Posey, Gravatt, and Colley (112) discovered three uredinia on young stems of *Ribes hirtellum* which resulted from natural infection in an outbreak area. Artificial inoculations on young stems of the same species with æciospores produced 18 more uredinia. A single stem infection was produced by Gravatt in the greenhouse upon a young seedling of *R. fasciculatum* (Pl. V, fig. 2). Æciospores were used in this case also. While the tender stem was completely girdled, it survived long enough to form wood and finally completely outgrew the disease. Since then Taylor has successfully inoculated with æciospores the stems of young seedlings of *Ribes missouriense* and of *R. americanum* in the greenhouse. York has infected stems of young *R. glandulosum* plants with æciospores and urediniospores out of doors, and has found natural infections on the same species and on *R. cynosbati*. He has infected a young stem of a 2-year-old plant of *R. cynosbati* with æciospores in the greenhouse.

RELATION OF STOMATA TO THE INFECTION OF RIBES.

A number of investigators of the Uredinales have stated that æciospore and urediniospore germ tubes obtain entrance to their hosts through the stomata (34, 70, 110, 149, 171).

As heretofore stated, *Cronartium ribicola* infects the *Ribes* plant on the lower side of the leaf mostly. Less frequently it infects the petioles, floral bracts, and cotyledons. It may infect young stems. Infection never occurs on the upper surface of the leaf. Examination of a number of different species of *Ribes* has been made by members of the Office of Investigations in Forest Pathology. Data on the stomata may be summed up as follows:

Stomata were present in large numbers on the lower surface of leaves of all species examined. Stomata were present in small numbers on the upper surface of leaves of *Ribes cereum* (60, 78), *R. inebrians* (60, 78), *R. odoratum* by Marshall, *R. orientale* (160), and

³¹ York, H. H. Op. cit.



LEAVES AND PLANT OF RIBES, SHOWING INFECTIONS OF CRONARTIUM RIBICOLA.

FIG. 1.—Upper surface of a leaf of *Ribes cynosbati* infected by *Cronartium ribicola*. Early stage of dying of the leaf tissue. FIG. 2.—Seedling plant of *Ribes fasciculatum* with stem infected by *Cronartium ribicola* as a result of inoculation with aeciospores. FIG. 3.—Upper surface of an infected leaf of *Ribes reclinatum*, horticultural variety Smith. This is quite resistant. Leaf tissue already dead. FIG. 4.—Upper surface of infected leaf of *Ribes vulgare*, horticultural variety Palluau. Quite resistant. A more advanced stage in death of attacked leaf tissue. Printed by J. M. Shull.

R. vulgare by Marshall. None were found by Unger (176) on the upper surface of leaves of *R. alpinum* nor by Taylor on *R. americanum*, *R. aureum*, *R. carrieri*, *R. culverwellii*, *R. fasciculatum*, *R. nigrum*, *R. reclinatum*, *R. speciosum*, and *R. (tenuiflorum) aureum*. Stomata were found only on the lower surface of cotyledons of *R. fasciculatum* and *R. missouriense*, the only ones examined by Taylor. Stomata were found by Taylor to be not uncommon on petioles of *R. americanum*, *R. aureum*, *R. carrieri*, *R. culverwellii*, *R. hirtellum*, *R. inerme*, *R. nigrum*, *R. odoratum*, *R. reclinatum*, *R. sanguineum*, *R. speciosum*, *R. succirubrum*, *R. (tenuiflorum) aureum*, and *R. vulgare*. None were found on petioles of *R. curvatum* and *R. fasciculatum*. Janczewski (60) states that stomata are present on the young stems of *R. petraeum*. A few stomata were found on young stems of *R. aureum*, *R. hirtellum*, *R. nigrum*, *R. odoratum*, *R. reclinatum*, *R. succirubrum*, *R. (tenuiflorum) aureum*, and *R. vulgare*. None were found on the stems of *R. carrieri* and *R. fasciculatum*. These findings compare well with the inoculation results, if stomata are the avenue for infection. It is perhaps to be expected that infection may be produced on the upper surface of the leaves, but only very rarely. Colley (20) found young uredinia forming in the substomatal spaces, which would indicate that infection took place in that vicinity and presumably through the stomata. York³² found germ tubes of æciospores entering the stomata of leaves of *Ribes cynosbati*, *R. glandulosum*, and *R. nigrum*.

VARIATIONS IN APPEARANCE ON RIBES LEAVES.

The study of great numbers of *Ribes* leaves infected in the greenhouse and of very numerous specimens of diseased leaves collected in the field from Maine to Minnesota, during the past ten years, has revealed some distinct variations in the appearance of the fungus and of the diseased leaves of different species and varieties of *Ribes*. Previous study of such differences seem to have been made chiefly by Hennings (52, 53).

BLISTERY APPEARANCE OF THE UREDINIA.

In August, 1916, there occurred a very hot, dry period in New England. This was followed by the finding of a few very peculiar-looking uredinia on *Ribes nigrum* and *R. vulgare*. Under a hand lens, the uredinia were not of the usual mealy appearance, but looked more like tiny blisters. Examination showed that the epidermis of the leaves had become toughened, so that the uredinia did not burst through it, as they usually do, but pulled it loose from the inner leaf tissues and in this way actually formed small blisters. The urediniospores never broke through it. From the weather conditions preceding and at the time this occurred it is believed that the dry, hot weather rendered the epidermis tougher than usual. It is a rare occurrence, as only a few cases have been noted. In 1916, one specimen came from each of the States of Massachusetts, Maine, and Vermont. In 1917, a single case was found in New Hampshire. Hedgcock noted this in 1919 upon artificially inoculated *Ribes* bushes on Block Island. Recently, blisters have been noted on *R. aureum* and *R. fasciculatum* in the greenhouse.

³² York, H. H. Op. cit.

DISTRIBUTION AND SIZE OF THE SORI AND COLONIES.

It has been found that *Cronartium ribicola* forms its uredinia and telia upon each species of *Ribes* in a manner which in general is characteristic of that host species (Pls. IV; V, figs. 1, 3, and 4; and VI). This was noted in 1902 by Hennings (52, 53), who described some of the more striking variations. Like all general statements, the following are subject to individual variations from the normal or average condition for the host species. A statement by Hennings (52, p. 130) indicates the degree of variation discernible to a keen observer:

It is especially noticeable that the fungus, according to the character of the leaves of various species of *Ribes*, shows great variations in the form and color of the spots produced on the leaves, the form and size of the sori, and the size of the telial columellæ, so that a new observer would assume that several of the fungus forms were specifically distinct.

In general, on species which are closely related, or which closely resemble each other, the fungus behaves in a similar manner. Some of the more striking variations are described as follows:

RIBESIA.³³—*Ribes petraeum* and var. *atropurpureum*: Sori close together and evenly distributed over the spots; spots large, soon overrunning a large part of the leaf surface.

Ribes rubrum vars. *petrowalskyanum*, *pubescens*, and *sibirica*: Very scant sori, located beside large veins of leaf; var. *scandicum* has abundant sori, close together, generally distributed.

Ribes triste: Sori clustered on definite spots; spots small, widely separated.

Ribes vulgare: Sori not plentiful, clustered on spots; spots small and isolated (Pl. IV, fig. 3; V, fig. 4).

HERITIERA.—*Ribes coloradense*: Sori thickly clustered on diffuse spots.

Ribes glandulosum: Sori usually thinly scattered over large diffuse spots or entire leaf surface, telia very slender and long (Pl. VI, fig. 1).

Ribes erythrocarpum: Sori plentiful, clustered.

CALOBOTRYA.—*Ribes glutinosum*: Sori thickly clustered in local areas.

Ribes nevadense: Sori thickly grouped on local spots; spots large and distinct.

Ribes viscosissimum: Sori isolated, scattered over entire leaf surface.

SYMPHOCALYX.—*Ribes aureum* and vars. *tenuiflorum* and *palmatum*: Sori abundant, closely grouped in rather distinct spots which usually are well separated from each other (Pl. IV, fig. 1).

Ribes odoratum: Sori abundant, closely grouped in spots usually well separated from each other.

AROPHYLLUM.—*Ribes cereum*: Sori clustered on definite rounded spots which soon die.

Ribes inebrians: Sori on rounded spots.

EUCOREOSMA.—*Ribes americanum*: Sori sparse and scattered, on small irregular spots which redden and die; heavy infection rare; telia short, one-half to 1 mm.

Ribes bracteosum: Sori plentiful, on large diffused spots or patches of leaf surface.

Ribes nigrum (Pl. IV, fig. 4) and vars. *aconitifolium*, *fasciculatum*, "*folio argentea*": Sori crowded densely, often over entire leaf surface, vigorous; telia abundant, reaching 2 mm. in length.

Ribes viburnifolium: Sori scant, dead spots form early.

³³ The species of *Ribes* are grouped according to the arrangement of Janczewski (60).

GROSSULARIOIDES.—*Ribes lacustre*: Dead spots formed early on infected leaves; sori sparse or diffuse, irregular spots; telia rather scattered.

GROSSULARIA.—*Ribes lobbi*: Sori thickly crowded on rounded spots, telia well developed.

Ribes menziesii: Sori sparse on small irregular spots.

Ribes speciosum: Sori seated closely together on large rounded spots, telia rather short.

EUGROSSULARIA.—*Ribes alpestre*: Sori thickly crowded on large rounded spots, telia short.

Ribes curvatum: Sori crowded on rounded spots on young leaves, on irregular spots on old leaves; telia quite plentiful; spots with reddened edges late in season.

Ribes cynosbati: Sori plentiful on definite spots, which are usually rounded (Pl. V, fig. 1): spots sometimes wedge shaped, lying between two branching veins of the leaf; telia crowded in small groups, 1 to 1½ mm. long, rarely over entire leaf surface.

Ribes divaricatum: Sori scattered on rounded spots.

Ribes missouriense: Sori crowded on rounded indefinite spots on young leaves, densely crowded on small leaves, dead irregular spots on old leaves.

Ribes leptanthum: Sori very scant; dead spots appear so early that uredinia can form with difficulty, often only one uredinium on a spot, many spots without sori; produces the least sori of any species yet noted.

Ribes hirtellum: Sori usually crowded thickly on small spots; uredinia on small rounded spots; telia small, crowded densely; on older leaves, on small indefinite, irregular spots bounded by veinlets; spots sometimes purplish on the edges.

Ribes oxycanthoides: Like *R. hirtellum*.

Ribes reclinatum: Sori rather sparse, on small irregular spots of dead tissue. There is a tendency toward a reddening or purpling of the edges of the spots on old leaves. (Pl. V, fig. 3.)

Ribes rotundifolium: Sori crowded on small irregular spots. The spots die early and are likely to become reddish around the edges even on rather young leaves. It is rather rare for the entire leaf to become covered with sori.

Ribes setosum: Much like *R. cynosbati*.

HEMIBOTRYA.—*Ribes fasciculatum* vars. *chinense* and *japonicum*: Sori densely crowded on large rounded spots.

DIACANTHA.—*Ribes diacantha*: Sori on rounded spots.

Ribes giraldii: Sori scattered on rounded spots.

In general, it may be said that *R. nigrum* and its varieties is the optimum host species among the *Ribes* for *Cronartium ribicola*. *Ribes aureum* and *R. odoratum* and their varieties are perhaps next to *R. nigrum* in favoring the growth of the fungus. *R. reclinatum* does not take the disease readily, but is by no means immune to it. In fact, no species or variety yet fully tested is entirely immune. *R. leptanthum* probably produces fewer sori for the extent of infection than any other species. This is caused by the very early death of the infected tissue.

PALE COLOR OF INFECTED SPOTS ON THE LOWER SURFACE OF RIBES LEAVES.

The production of sori on an infected spot on the lower surface of *Ribes* leaves is often preceded for one, two, or three days by a pale

coloration (Pl. VI, fig. 2). This is most likely to occur on young leaves. It is a fairly certain symptom of a successful inoculation.

Striking cases of the preservation of the normal green color in the infected areas, while the rest of the leaf is etiolated, have been noted a number of times.

PALE COLOR OF INFECTED SPOTS ON THE UPPER SURFACE OF RIBES LEAVES.

Numerous young *Ribes* leaves inoculated in the greenhouse developed pale spots on the upper side of the infected leaves (Pl. V, fig. 1). These varied from nearly white to yellow. Similar spots are often seen in the field. Some species of *Ribes* seem to be more likely to develop these spots than others. Among those showing this etiolation as a result of infection by *Cronartium ribicola* may be mentioned: *Ribes aureum* and its varieties, *R. cereum*, *R. cynosbati*, *R. divaricatum*, *R. erythrocarpum*, *R. fasciculatum*, *R. glandulosum*, *R. hirtellum*, *R. inebrians*, *R. inerme*, *R. leptanthum*, *R. nevadense*, *R. nigrum*, *R. odoratum*, *R. reclinatum*, *R. rotundifolium*, *R. setosum*, *R. speciosum*, *R. triste*, and *R. vulgare*. These spots seem to be produced by conditions existing in the immature *Ribes* leaf when attacked by the fungus very actively.

REDDENING OF INFECTED SPOTS ON RIBES LEAVES.

Certain species of *Ribes* react to infection by *Cronartium ribicola* by a reddish or purplish coloration around the edges of the infection. This is common with some species, while others apparently must have the leaves at a certain stage of maturity for this coloration to occur. *Ribes americanum*, *R. curvatum*, *R. rotundifolium*, *R. viburnifolium*, *R. glandulosum* (old thick leaves), *R. cynosbati* (old thick leaves), *R. hirtellum* (old thick leaves), *R. oxyacanthoides*, *R. reclinatum*, and *R. missouriense* develop the red color in the order named.

DEAD AREAS OF INFECTED LEAF TISSUE.

Where the attack of *Cronartium ribicola* is intense, areas of the oldest infected tissue of the diseased leaves collapse and die (Pl. V, figs. 3 and 4; Pl. VI, fig. 3). The different species of *Ribes* vary much in this respect, some developing dead spots very quickly and some doing so only after considerable time. *Ribes nigrum* usually resists death tenaciously. When a spot dies it is commonly a large one and soon results in the premature fall of the affected leaf. At the other extreme is *R. leptanthum*. With this species the infected spots die very quickly, even before uredinia can form (147). Less than 10 per cent of these spots produce any uredinia or telia, and those few spots bearing sori usually have only from one to several stunted sori. All species of *Ribes* tested have sooner or later developed dead spots. Just how much secondary fungi contribute to the killing of host tissues is entirely unknown.



LEAVES OF RIBES INFECTED WITH CRONARTIUM RIBICOLA, SHOWING DIFFERENT TYPES OF INFECTION.

FIG. 1.—Infected leaves of *Ribes glandulosum*, showing lower surfaces; the sparsely scattered telia are well distributed over the entire surface. Etiolation caused by the disease is also evident. $\times \frac{5}{8}$. FIG. 2.—Lower surfaces of leaves of *Ribes* sp., showing etiolated spots where infection has taken place, two days before uredinia were formed. $\times \frac{5}{8}$. FIG. 3.—Lower surfaces of infected leaves of *Ribes aureum*, showing the disease distributed in local spots mostly well separated from one another. On the right side of the right leaf a large area of leaf tissue has died. Etiolation from the disease is evident. $\times \frac{5}{8}$.

THE UREDINIA AND UREDINIOSPORES.

GENERATIONS OF UREDINIA.

In 1918, Pennington³⁴ and Snell investigated the number of generations of uredinia of *Cronartium ribicola* produced in the Adirondack region, and the weather conditions that might influence their production. *Ribes rotundifolium*, *R. cynosbati*, and *R. glandulosum* were the principal species used in these investigations. The observations were made in four different localities within 10 miles of the town of Lewis. There were seven periods of uredinial production in 1918. The first generation began on May 28, reached its climax about June 12, and then gradually fell off until June 26 to 28, when the second appeared. The third began to appear about July 12 and reached its maximum on July 19 to 22. The second and third crops of uredinia were located almost entirely on those leaves which were originally infected by æciospores or those adjacent to them. Drought from July 18 to July 28 caused most of the infected leaves to drop from the bushes of *Ribes cynosbati* and *R. rotundifolium*, leaving them partly or entirely defoliated. The fourth crop was much smaller, but well marked, and came on August 19 and 20. The fifth generation came on September 12 to 15; it would have been more abundant had not a heavy frost on September 11 killed all the leaves of *R. glandulosum* and some on the other two species of *Ribes*. The sixth crop appeared especially on the second crop of leaves of the earlier defoliated bushes and on fresh green leaves of bushes in sheltered situations. The seventh generation appeared on October 15 to 18 on leaves ready to fall. A study of the weather conditions, as noted at Lewis, showed that about two weeks before the appearance of each new generation there was a period of at least 24 hours of rainy and cloudy weather. But not all such periods were followed by new crops of urediniospores.

In 1919, Pennington³⁴ found that the generations of uredinia were not as distinct at Lewis, N. Y., as they were in 1918. The first four, on May 23, June 21 and 22, July 3, and July 20, respectively, were well defined. A fifth on August 7 and a sixth on August 21 were distinct on some bushes, but in most places overlapped. In general, after August 1, the generations overlapped, because of rain every day or two, so as to become confused with each other.

SEASON OF PRODUCTION OF THE UREDINIA.

Like the æcial season, the beginning of the uredinial season of production varies with conditions somewhat, though to a less marked degree. May 16 is the earliest recorded date for mature uredinia. A week after this is the more usual time for them to be found in most

³⁴ Pennington, L. H. Op. cit.

localities. (For range of observed dates in various sections of North America, see Table V, p. 72.)

In the White Mountain region of New Hampshire, York ³⁵ found fresh urediniospores in 1918 on May 16 and as late as November 17. Urediniospore production there continued on some bushes for 185 days, while under average conditions it continued about 120 days. At this place the following species were under observation: *Ribes cynosbati*, *R. glandulosum*, *R. lacustre*, *R. nigrum*, *R. odoratum*, *R. oxyacanthoides*, *R. reclinatum*, *R. triste*, and *R. vulgare*. Urediniospore production continued the longest time (185 days) on *R. nigrum* and the shortest time (65 days) on *R. lacustre*. In general, it can be stated that the urediniospores continue to form as long as there are susceptible leaves on the *Ribes* bushes of a given locality.

York ³⁵ found that the maximum urediniospore production in 1918 occurred about July 14 to 16 and in 1919 about July 25 to 26. After these dates came the maximum sporidia production, and then the bushes became almost completely defoliated.

DISTANCE OF DISSEMINATION OF THE UREDINIOSPORES.

In the early work upon *Cronartium ribicola* in North America the wide dissemination of the fungus from a given center appeared to take place by means of the urediniospores. Stewart and Rankin (151), who had an especially good opportunity to study this point, concluded that the urediniospores were blown at least one-half mile. Early general observations of the spread of this stage indicated that a wet season greatly favored it, while a dry season just as markedly retarded it.

McCubbin (87) found that urediniospores fall in still air about 8 feet in 5 minutes. He calculated that a 30-mile breeze would carry them $2\frac{1}{2}$ miles in this time. Theoretically they may be distributed long distances if located on a hill or if picked up by convection air currents. But most of these spores are actually produced within 2 feet of the ground in most localities, so that they are not picked up by the wind as readily as the æciospores, which are commonly produced a number of feet above the ground. When set free, the urediniospores adhere in masses, so that they are not as readily blown by the wind as are the æciospores, which tend to fall apart when dislodged from the æcium.

York and Overholts (cited in Spaulding, 145) in 1918 at North Conway, N. H., found urediniospores in spore traps up to 300 yards distant from the known source. This was where rain was plentiful practically all summer. Observations on infections of *Ribes glandulosum* and *R. cynosbati* plants indicated that the disease spread by urediniospores up to 100 yards. In some cases where the bushes

³⁵ York, H. H. Op. cit.

were protected by surrounding trees or other objects, the rust spread little or not at all. In other words, where moisture was plentiful through the season, the distance of spread by urediniospores was governed by factors controlling the free access of the wind. In Essex County, N. Y., drought prevailed through July and August in 1918. Here Pennington³⁶ worked with spore traps and Snell (128) gave special attention to a study of the spread of the uredinial stage on *Ribes*. The *Ribes* of this section were largely *Ribes rotundifolium* and *R. glandulosum*. Here the rust spread in most instances only to adjacent leaves from those first infected on a given bush. The spore traps here caught urediniospores only at a very short distance, 50 feet or less.

In 1919, York (cited in Spaulding, 146) caught urediniospores up to a distance of 3,400 feet in an open location, but they did not germinate. Urediniospores caught at 3,200 feet did germinate. Pennington³⁶ caught urediniospores up to 156 feet.

AGENTS DISSEMINATING THE UREDINIOSPORES.

Wind has been supposed to be the principal agent distributing the urediniospores of *Cronartium ribicola*. While this supposition is correct in the main, other agents are concerned in the matter.

Hennings (53) says that sprinkling diseased *Ribes* plants with a strong stream of water carries urediniospores from plant to plant. Rain accompanied by high wind is known to carry spores of some plant diseases (38, 44). It is entirely possible for this to occur with any spore capable of wind distribution, as in the present case.

In 1917 Gravatt and Marshall (45) made studies in the experimental greenhouse at Washington, D. C. They found that weevils, snails, slugs, and sow bugs fed on the uredinia and telia of *Cronartium ribicola* on the diseased plants. The ingested urediniospores lost their viability to a large extent, but not entirely.

In the same year Gravatt and Posey (46), working at Kittery Point, Me., found that gipsy-moth larvæ feed quite freely upon leaves of *Ribes hirtellum* and *R. vulgare* and that in some cases the only infected leaves were those which had been partially eaten by insects, indicating that they carried the spores which infected the leaves. The insects were found carrying viable urediniospores on their bodies. There can be no doubt that these insects play an important rôle in the local distribution of this fungus within the gipsy-moth infested area.

Studies by Snell (127) at Lewis, N. Y., in 1918, show that a large number of insects visit *Ribes* plants during the season when the rust is present upon the leaves. The spore-laden insects were inclosed in chambers with the tips of *Ribes glandulosum* plants, and infection

³⁶ Pennington, L. H. Op. cit.

resulted in due time. Many of these insects are, of course, accidental visitors, but quite a number feed or breed upon the *Ribes* plants. All of those which frequent the *Ribes* bushes by preference may carry many spores of both uredinia and telia. Such insects would be most likely to spread the disease, since upon leaving one *Ribes* plant they would seek another, thus scattering the spores exactly where they could start new colonies of the disease. But the accidental visitors, in a locality where *Ribes* bushes are abundant, could also spread the spores locally, but in a much more indiscriminate manner, so that but a very small percentage of the spores would ever reach leaves of *Ribes*.

Aside from carrying spores on their bodies, some insects feed directly on the uredinia and telia and a few of the excreted spores are known to retain their viability. Still other insects may be leaf eaters and ingest the rust spores only accidentally. These would be of minor importance in spreading the disease.

At Lewis, N. Y., where the *Ribes* bushes overhang narrow cattle paths which wind through a heavy cover of blackberry, raspberry, and other low shrubs, observations by Pennington and Snell indicate that cattle, sheep, horses, dogs, and berry pickers may carry the urediniospores from an infected bush to neighboring healthy ones.

The remarks on the carrying of æciospores by automobiles, steam trains, and electric cars on page 36 apply also to some extent to the urediniospores.

GERMINATION OF THE UREDINIOSPORES.

The urediniospores of *Cronartium ribicola* have been generally found to be erratic in germinating. At one time excellent germination occurs; at another, none at all. In the greenhouse experiments it seems that urediniospores produced in newly formed uredinia have greater infective power than those produced later in the same uredinia. Such early urediniospores seem to give as good results as fresh æciospores. The former are usually produced in limited quantities while the latter are usually abundant. This results in a more liberal use of the latter, so that a fair comparison of the two is not possible from the usual inoculation work. Gravatt made comparative tests and concluded that æciospores and urediniospores from newly open sori were about equal in infective power. More such tests should be made before any conclusive statement is made on this point.

Gravatt and York found that newly matured urediniospores produced out of doors were decidedly more viable than older ones. This agrees with general experience in making inoculations in the greenhouse.

Gravatt found that cooling the urediniospores on ice stimulated germination. Uncooled spores gave 15 to 23 per cent germination

while ice-cooled ones of the same lot gave 25 to 54 per cent germination. Marshall found the same stimulating effect from a temperature of 23° F. upon urediniospores on *Ribes* leaves stored outside a window, as compared with those on leaves kept at room temperature.

Posey dried infected leaves of *Ribes nigrum* in the hot July sun for four hours. Urediniospores from these gave germination ranging from 3 to 45 per cent, with an average of 17 per cent. Spores from other leaves collected at the same time and dried inside in the shade gave 3 to 90 per cent germination, an average of 47 per cent. During dry, hot weather it has been found that the viability of the urediniospores out of doors is very low.

Duff (30), in studying the factors affecting their viability, found that exposure to bright sunlight reduces their germination, the ultra-violet rays being the destructive agent. Their viability appears to him to be low. Three days after collection less than 50 per cent germinated in distilled water. In about two weeks germination was negligible even when stimulated by cooling to 2° to 5° C.

Pennington³⁷ made germination tests of newly-matured urediniospores of *Cronartium ribicola* produced naturally in the vicinity of Lewis, N. Y., from early June until late in the autumn in hanging drops of tap water. During the first two weeks of June (frequent rain) the percentage of germination was high. From June 16 to 28 no tests were made. On June 29 and July 1 (rather dry) only 1 per cent germinated. After this time, many tests were made with spores from various localities. By July 14 (very hot alternating with some rain) less than one-third of 1 per cent germinated, and from July 22 to 26 (hot and dry) less than one-tenth of 1 per cent. Fresh yellow spores kept in an ice box gave no better results. On August 1 (rain July 29 and 30) 5 per cent germinated. After this (decidedly more rain) from 10 to 40 per cent germinated. The viability of these spores seemed to be greatly decreased by hot, dry weather and increased by cool rainy spells at the time they were produced. When the number of spores produced decreased because of hot, dry weather, their rate of germination also decreased and vice versa.

Doran (28) found that the limiting temperatures for the germination of urediniospores are: Minimum 8°, optimum 14°, and maximum 25° C. He calls attention to the fact that—

There is apparently a relation between the season when spores occur and their temperatures for germination. The aeciospores of *Cronartium ribicola* occur in the spring when the average temperature is lower than in the summer, the season of occurrence of the urediniospores of this fungus. The aeciospores of this fungus have a minimum temperature for germination, which is 3° C. lower than that of the urediniospores; an optimum 2° C. lower than that of the urediniospores; and a maximum 6° C. lower than that of the urediniospores.

³⁷ Pennington, L. H. Op. cit.

Germination of fresh urediniospores usually takes place readily in tap water. Gravatt found that distilled water gave poorer germination than tap water. Colley (20) found that the germ tube pushes through the exospore without the aid of a germ pore. The contents of the spore soon pass into the young germ tube, which may extend some distance over the surface of a *Ribes* leaf. Entry to the interior of the leaf appears to be through the stomata. The urediniospores germinate in about five and one-half hours (28) in drops of distilled water on glass slides.

During germination studies in 1918, York³⁸ occasionally found germinating urediniospores which formed secondary conidia. An investigation of the conditions causing their formation showed that newly formed urediniospores usually do not produce the secondary conidia in tap water, while old urediniospores were more likely to produce them. The following species produced them, the frequency increasing in the order named: *Ribes lacustre*, *R. cynosbati*, *R. vulgare*, *R. reclinatum*, and *R. nigrum*. Urediniospores from *R. glandulosum* did not produce secondary conidia. Urediniospores exposed in bags of mosquito netting out of doors gave especially abundant secondary conidia. Urediniospores from *R. nigrum* produced secondary conidia in weak solutions of ammonia, maltose, tannic acid, gallic acid, malt extract plus gallic acid, lactose plus tannic acid, and lactose plus gallic acid. They were especially abundant in the last solution. They were not produced in pine decoction, weak solutions of ether, lactose, maltose plus tannic acid, and maltose plus gallic acid. A limited number were produced in water. They form on the ends of the germ tubes or laterally and are capable of producing a germ tube themselves. Similar secondary conidia have been noted by Tulasne (175) in cultures of *Cronartium asclepiadeum*, and they have been noted by Plowright (109) and Sappin-Trouffy (122) in other Uredinales.

LONGEVITY OF THE UREDINIOSPORES.

The first experiments in testing the longevity of urediniospores of *Cronartium ribicola* seem to have been carried out by McCubbin³⁹ in 1916. His manuscript account of these experiments follows:

The spores used for this series were all collected on the same day. They were dried on paper for a few hours and then placed in a number of small bottles plugged lightly with cotton, the contents of each bottle being available for a single inoculation. Half of these bottles were kept on a shelf in the laboratory, where they were dry and exposed to weak light, and the other half were placed under a bell jar on the soil in a garden, exposed to changes of humidity, temperature, and light.

At stated intervals a bottle was taken from each set and the spores within were shaken up with a small amount of distilled water. By the use of a small atomizer the suspension of spores was then sprayed on the under side of the leaves of small

³⁸ York, H. H. Op. cit.

³⁹ McCubbin has very kindly allowed the use of his unpublished data so as to make this account as complete as possible.

currant plants which had been previously set out in an isolated garden for the purpose. After inoculation the plants were covered for two days by a box having a glass lid. In all cases, water was sprinkled three or four times daily on the plants and on the inside of the box, to keep a high humidity. Unfortunately, during the whole of the period covered by this series of inoculation the weather was exceedingly hot and dry, and it was evident from a study of field conditions that infections could take place at this time only with the greatest difficulty. The adverse nature of the weather conditions will serve to explain the meager results.

The only positive result from this experiment was that the spores would retain their power of infection for a period of nine days at least; but so many failures occurred all through the course of the work that this period can not be regarded as establishing a maximum limit of life.

It is interesting to note that the spores kept outside underwent a complete decolorization in two days, whereas those stored in the laboratory retained their normal color, with but little change throughout the whole time of the experiment.

The inconclusive results obtained from the first set of inoculations in the field led to another later attempt with plants kept in the laboratory, for this purpose a number of small plants being used from which the leaves had been stripped, so as to induce the formation of secondary foliage. The methods employed in this case were the same as for the first set, except that after inoculation the shoots were kept covered and moistened for the usual 48 hours inside large glass jars. (See Table IV.)

TABLE IV.—*Inoculation of currants with uredospores of different ages.*

Series.	Age of spores (days).	Date of inoculation, 1916.	Number of leaves used.	Date of examination, 1916.	Result.
I.....	2	August 31.....	16	September 19.....	5 pustules on 2 leaves.
II.....	4	September 2.....	16	September 22.....	67 pustules on 11 leaves.
III.....	7	September 5.....	16	September 25.....	No infection.
IV.....	8	September 6.....	14	September 26.....	10 pustules on 5 leaves.
V.....	11	September 9.....	11	September 29.....	8 pustules on 2 leaves.
VI.....	13	September 11.....	16	October 1.....	2 pustules on 2 leaves.
VII.....	18	September 16.....	5	October 6.....	No infection.
VIII.....	24	September 22.....	7	October 12.....	Do.
IX.....	27	September 25.....	7	October 15.....	Do.
X.....	31	September 29.....	7	October 19.....	Do.

The results from these inoculations were somewhat better than those from the first set; infections were obtained from spores kept for 13 days after collection, as shown in the tabulated record. It is still thought that this period is far below the maximum period for which the spores will retain their vitality.

In 1917 Gravatt and Taylor made a series of tests of urediniospores together with æciospores and teliospores. (See p. 38 for details of the experiment.) They were tested weekly beginning May 8. June 16 gave the last germination in lot A, while lot B persisted until July 2. Although germination persisted longer in lot B, it weakened decidedly somewhat earlier and was poorer practically throughout the test. (See Table II, p. 38.)

In 1918, Duff (30) experimented on the longevity of urediniospores placed in a refrigerator at 2° to 5° C. two weeks after collection and tested in hanging drops of distilled water. He states that when placed in the refrigerator—

A negligible percentage of spores were germinable, but reduction in temperature stimulated them to greatly increased germination. By this means a continually

decreasing percentage of spores were kept in a viable condition, until after a lapse of a further period of about three weeks the number that germinated readily was negligible once more. Before the end of four weeks the spores had ceased to germinate.

Extensive tests of the longevity of urediniospores were made by York, Overholts, and Taylor.⁴⁰ In one experiment leaves of *Ribes nigrum*, *R. vulgare*, and *R. reclinatum* were placed in bags of mosquito netting with the urediniospores outward. The bags were placed on three stakes at 6-inch intervals, the lowest one touching the ground and the highest 5 feet above the soil. The lowest spores remained viable only 6 to 9 days, while the upper ones were viable longest, 65 days. A 2-day rain began the day after starting the experiment and again a 1-day rain two days later. The urediniospores from *R. nigrum* remained viable longest. Again infected leaves of *Ribes nigrum*, *R. vulgare*, *R. cynosbati*, and *R. glandulosum* were put in open boxes and exposed for 4 hours to the early morning sun. Viability persisted only 15 days. The urediniospores from *Ribes nigrum* remained viable longest. Urediniospores on pulled bushes of *Ribes glandulosum* and *R. cynosbati* hung in the bright sun remained viable only 4 days. Spores on leaves of *Ribes nigrum* dried in a plant press, then put in tight Mason jars and stored in an ice-box remained viable 80 days. Successful inoculations were made with urediniospores collected 270 days previously and also with urediniospores from dead, overwintered leaves of the previous season. The age of the spores is not known, but they were certainly overwintered spores (180). It was found that viability in tap water persisted at least 169 days when the spore-bearing leaves were air dried and kept under slight pressure between sheets of heavy glazed paper. When kept out of doors but protected from rain, they retained viability for 100 days.

In 1918 Pennington⁴¹ made a number of tests of the longevity of urediniospores. In July and August urediniospores on *Ribes* leaves brought into the laboratory and air dried lost their viability within a week when tested in drop cultures of tap water. On September 25 many *Ribes* leaves were collected and allowed to dry between sheets of paper. The second day urediniospores from these leaves gave 50 per cent germination when tested as above. The leaves were left in the dry air of the laboratory. The spores decreased in viability until November 26 when but 1 per cent germinated. After that there was no germination.

These results, showing a longevity ranging from 7 to 270 days under varying conditions, indicate the sensitiveness of the urediniospores to external factors. In addition it is quite possible that the physiological condition of the host plant also has a profound effect upon these spores.

⁴⁰ York, H. H., Overholts, L. O., and Taylor, M. W. The longevity of the sporidia of *Cornartium ribicola*. Seen in manuscript. To be published in *Phytopathology*.

⁴¹ Pennington, L. H. Op. cit.

THE TELIA AND TELIOSPORES.

GENERATIONS OF TELIA.

In 1918 Pennington ⁴² made observations upon the generations of telia at Lewis, N. Y. This was a season very favorable for the occurrence of distinct waves of spore production. The first generation of telia appeared on June 28 with and following the second crop of uredinia. They were present throughout the rest of the season, but in the greatest abundance with and immediately following a new generation of uredinia. As compared with the uredinia, they were produced in relatively greater abundance with each succeeding generation. There were six distinct waves of telial production.

SEASON OF PRODUCTION OF THE TELIA.

The date when the first telia are produced varies from year to year with the earliness of the season. The earliest of which we have definite record is June 2, 1918, at North Conway, N. H. Table V (p. 72) gives data for the different regions of North America. The telia are formed until the Ribes leaves fall in the autumn. Drought is likely to cause premature shedding of diseased Ribes leaves soon after the first telia form. This greatly limits the production of new telia.

DISTRIBUTION OF THE TELIOSPORES.

Because the teliospores are produced in more or less compact columellæ they are normally not separated from the host plant. They do become distributed somewhat, however. Gravatt and Marshall (45) found that slugs eat telial columns from rusted Ribes leaves; also that sow bugs carry broken columns on their bodies. There seems to be no reason why insects and other animals may not do likewise.

The telia are sometimes mechanically broken off and blown about by the wind.

Diseased Ribes leaves fall to the ground and are blown about by the wind. Often they are broken into small pieces which may be blown long distances. In fact, York ⁴³ found such bits of dead leaves in his spore traps 200 feet distant from the nearest Ribes bush. Telia on dead leaves kept out of doors in the shade are known to retain viability for 65 days, so that in this way the disease might appear in very unexpected places on pines at a greater distance than the sporidia are carried in a viable condition.

GERMINATION OF THE TELIOSPORES.

The teliospores germinate readily in tap water and produce sporidia in 6 to 12 hours.^{43,44} Each spore produces normally a 4-celled pro-

⁴² Pennington, L. H. Op. cit.

⁴³ York, H. H. Op. cit.

⁴⁴ York, H. H., Overholts, L. O., and Taylor, M. W. Op. cit.

mycelium. Each cell regularly puts forth a stout sterigma on which the very thin walled, globular sporidium soon develops. The sporidium has a tiny papillalike swelling where it was attached to the sterigma. The sporidia are 8 to 10 microns in diameter (20). The germ tubes of the teliospores, if developed under water, may not form promycelia but extend elongated hyphæ (20). Under favorable conditions a high percentage of the teliospores may germinate, but because of their aggregation into columellæ it is impossible to make an exact count of the germinating spores. Cooling on ice stimulates viability markedly.

LONGEVITY OF THE TELIOSPORES.

The longevity of the teliospores of *Cronartium ribicola* does not seem to have received as much attention as that of the æciospores and urediniospores. Gravatt and Taylor made tests with teliospores in 1917 similar to those described as made by them with æciospores and urediniospores. (See Table II.) Weekly tests showed that germination persisted in lot B 35 days, while it lasted 56 days in lot A. Saprophytic fungi attacked the lot kept on the window sill, so that the test probably does not show the longevity of healthy teliospores.

York ⁴⁵ in 1918 found that teliospores were still capable of germination in tap water after being kept on the plucked leaves 65 days out of doors in the shade. A similar test of teliospores kept in the dark in the laboratory gave germination for 90 days.

THE SPORIDIA.

SEASON OF PRODUCTION OF THE SPORIDIA.

The sporidia may be produced as soon as the telium is mature, if there is sufficient moisture in the air for a number of hours.

The telia may remain alive on dry dead leaves out of doors for more than 65 days, so that sporidia might be produced well into the winter in mild seasons, thus prolonging the danger season for pines.

DISTANCE OF DISSEMINATION OF THE SPORIDIA.

In work with spore traps by Pennington ⁴⁶ and Snell in 1918, sporidia were caught up to 60 feet from very heavily infected *Ribes* bushes. This was in the eastern Adirondacks, about 8 miles from Lake Champlain. Hundreds of pines were examined for infections. In no case was infection found on pines as far as 200 feet from *Ribes* plants. Pennington made a study of nine outbreaks in pines in the Adirondacks. The infection on pines was confined to an area within 100 to 200 feet of the *Ribes* plants which infected the pines.

⁴⁵ York, H. H. Op. cit.

⁴⁶ Pennington, L. H. Op. cit.

In 1919, Pennington (cited in Spaulding, 146) caught sporidia up to 294 feet distant, but they failed to germinate. Under favorable conditions, sporidia caught at a distance of 177 feet germinated, but none beyond this distance.

York,⁴⁷ working in the White Mountain region of New Hampshire, in 1918, found that sporidia were quite common in spore traps exposed 24 hours at a distance of 200 feet from the diseased *Ribes* bush. York (cited in Spaulding, 146) in 1919 caught sporidia, under favorable conditions, at 600 feet distance, which germinated.

The infection of pines is said by McCubbin (88) to depend on "(1) The nearness of cultivated *Ribes*, particularly black currants; (2) the number of wild *Ribes* present; (3) the moistness of the situation." York⁴⁷ concluded that these factors are "topographical features, direction of the wind when sporidia are produced, humidity of the air, precipitation, and the nature and density of vegetation between the *Ribes* and pines." Pennington⁴⁸ stated that weather conditions have much to do with the degree of infection that occurs on pines; cool, moist situations favor infection; intervening barriers of vegetation tend to limit infection; the amount of infection under given conditions varies directly as the extent of *Ribes* leaf surface and inversely as the square of the distance from *Ribes*. The writer (145) said the width of the *Ribes*-free zone around pines is largely to be governed by topographical features; direction of the wind prevailing at the time the sporidia are produced; humidity; age of the pines; exposure and species of *Ribes*; and the composition, height, and density of the vegetation between the *Ribes* plants and the pines. The experiments with the sporidia show that high humidity is necessary for these spores to live any length of time. It alone may very largely determine whether infection can take place.

A few specific instances show the effect of these factors in actual outbreaks. On July 10, 1917, on Gerrish Island, at Kittery Point, Me., Gravatt investigated the small trees of *Pinus strobus* within a radius of 15 feet of a bush of *Ribes hirtellum* to determine the spread of infection. The gooseberry was a small bush, having approximately 270 small leaves and there were no other *Ribes* near by to influence the result on pines. The ages of the pines were as follows: Two years, 12; 3 years, 17; and 5 years, 82; a total of 128 pines, none over 5 years of age. There were 77 separate infections on 54 diseased trees, 44 of these infections being on 2-year wood. As the oldest pines were 5 years old and most of the infections which occurred the year before were probably not detected, this infection of more than 40 per cent resulted from an exposure of only a little more than

⁴⁷ York, H. H. Op. cit.

⁴⁸ Pennington, L. H. Op. cit.

3 years to the disease. To judge from the results of the first five years, it is not likely that any of the pines within the 15-foot radius would remain alive at the end of 12 or 15 years. Pines outside the 15-foot radius from the bush showed only scattering infections. This was in a location well protected from strong winds.

In another case where *Ribes nigrum* was well exposed to the strong storm wind from the neighboring White Mountains, York found pine infections up to 600 yards distant from heavily diseased *Ribes* bushes.⁴⁹

In the outbreak at Kittery Point, Me., Posey found that a number of *Ribes nigrum* bushes so located that the wind had moderate access to them caused infection of *Pinus strobus* trees up to a distance of about 300 yards.

Our studies (146) of the distance of distribution of the various spore forms and of the distance that infection has actually occurred upon pines from known infected *Ribes* indicate that the *Ribes*-free zone should be, under average conditions, 200 to 300 yards in width. It should be much more where conditions are exceptionally favorable for transfer of the spores from *Ribes* to pine, i. e., near large bodies of *Ribes*, where there is no screen of vegetation over the *Ribes* or between the *Ribes* and the pines, or in exceptionally humid situations. The cultivated black currant (*Ribes nigrum*) should not be allowed in an infected pine district because of the special danger from it.

Studies by York⁴⁹ of the natural infections of pines show that the sporidia are blown along roads cut through heavy forest cover and that they do not reach pines located in isolated small pockets in the dense forest. Trapping of sporidia from *Ribes* located under dense cover of black alder yielded sporidia only up to a distance of 75 feet. Traps set 20 feet in the air and well above the cover, but directly over the *Ribes* bushes, caught no sporidia.

AGENTS DISSEMINATING THE SPORIDIA.

It is apparent that the sporidia produced by the teliospores of *Cronartium ribicola* are largely disseminated by the wind. Observations in various areas where white pines have become infected from neighboring *Ribes* bushes show plainly that this is the case. In such cases the infection is most intense nearest the *Ribes* bush acting as a center of infection. The degree of infection decreases as the distance from the center increases. Other conditions being equal, the distance of pine infections from the infection center is very short where there is a thick screen over and around that center, while the converse is true where the *Ribes* infection center is well out in the open. (See pp. 64 to 66 for data bearing on this matter.)

Minor disseminating agents are known, and their number will undoubtedly be increased by future investigations. The investigations of Gravatt and Marshall (45) in the experimental greenhouse

⁴⁹ York, H. H. Op. cit.

at Washington, D. C., showed that weevils, snails, slugs, and sow bugs feed on the telia. The voided teliospores retained viability in a few instances. This indicated that similar animals might be active agents in the local distribution of these spores out of doors. Investigations by Snell (127) in 1918 at Lewis, N. Y., showed that a number of different types of insects feed on rusted leaves of *Ribes* bushes and may serve as carriers of the sporidia directly from plant to plant, or indirectly by the voided teliospores. Marshall, in 1917, found that the moist sporidia allowed to dry on a feather are not easily dislodged therefrom, either by wind or by brushing of the feather on cloth. This suggests the possible carriage of sporidia by migrating birds in the fall for long distances. Their very short life, as determined by York (see pp. 67-68), however, probably prevents their causing infection of pines under these conditions.

The remarks on the carriage of æciospores by currents of air generated by fast-moving automobiles, steam trains, and electric cars also apply to the sporidia. (See p. 36.)

GERMINATION OF THE SPORIDIA.

Gravatt, Colley (20), and York, Overholts, and Taylor ⁵⁰ found that the sporidia germinate immediately in tap water under favorable conditions. They germinate like ordinary fungus conidia, by pushing forth a germ tube which is relatively large. They are capable of germination as soon as they reach full size, even though still attached to the promycelium. The germ tube normally develops until a mycelium is formed. In some cases the germ tube soon forms a secondary sporidium which in turn may germinate. The viability of the fresh sporidia is high, as many as 90 per cent germinating within 24 hours.

LONGEVITY OF THE SPORIDIA.

The sporidia of *Cronartium ribicola* are so thin walled and fragile in character that it seems self-evident that they are short-lived spores. This supposition has been proved to be correct by the work of York and Overholts in the summer and autumn of 1918 and of York and Taylor in 1919 (cited in Spaulding, 146). Colley (20) found in 1917 that fresh sporidia germinated readily in distilled-water cultures. York, Overholts, and Taylor ⁵⁰ dried the sporidia on glass slides and tested their viability after varying intervals. Very slight germination resulted after 10 minutes exposure by an open window at 66° F. when light rain was falling. None survived when exposed to bright sunlight for 10 minutes with a temperature of 77° F. Nor did they survive when pieces of *Ribes* leaves bearing the telia and sporidia were exposed to sunlight for 10 minutes at 85° F. and with a humidity

⁵⁰ York, H. H., Overholts, L. O., and Taylor, M. W. Op. cit.

of 30.5 per cent. In another experiment the sporidia were placed on the periderm of white-pine twigs of the same season's growth and on living leaves of *Pinus strobus* and *P. rigida*. They were then exposed dry at 66° F. and with a humidity of 90 per cent. None survived for 10 minutes. At 72° F. and a humidity of 69 per cent none survived for 10 minutes. They conclude that the sporidia can endure very little desiccation and are short lived under seemingly optimum conditions. Abundant moisture is necessary for infection of pines to occur.

HETERÆCISM OF THE SPORIDIA.

A number of tests have been made to learn whether *Ribes* might become infected by sporidia of *Cronartium ribicola*. Jaczewski (59) states that experiments have shown that they will not infect *Ribes* leaves. In 1913, Clinton, Stewart, and the writer (151) inoculated *Ribes nigrum* leaves with teliospores overwintered out of doors, but there were no infections. In 1912 the writer tested fresh teliospores without infection occurring (136). In 1917 Gravatt made several tests of fresh, sporidia-producing telia, but no infection resulted.

OVERWINTERING OF CRONARTIUM RIBICOLA.

Overwintering on Pines.

The generally accepted view has been that *Cronartium ribicola* lives over winter by means of the mycelium in the bark of living infected pines and by this means only (142). A number of writers have mentioned cases where their observations seemed to indicate the possible overwintering on infected *Ribes*, but nothing that could be accepted as real evidence was offered until the last few years. There is no question that the fungus overwinters chiefly in the infected living pine trees and has been carried in the dormant condition from continent to continent in young infected pines.

It has been discovered, as has been mentioned earlier, that *Cronartium ribicola* may overwinter as mycelium in infected branches cut from diseased trees late in the fall, or during the winter, and allowed to lie until spring. Then, if these cut-off branches lie close to damp soil or with the cut ends in a stream or pool, fresh vigorous æcia are produced (89). Still another phase of overwintering was discovered by Dosdall (29) in Minnesota. On April 19, 1918, a dead branch of white pine, bearing an infection which bore æcia in 1917, was collected. Germination tests in distilled water showed that 1 to 2 per cent of the old æciospores were still viable.

Overwintering on Ribes Plants.

Investigations of overwintering of *Cronartium ribicola* on *Ribes* plants, in Europe, seem to be limited to field observations. They

relate to instances where diseased *Ribes* bushes were found widely separated from *Pinus strobus* or from all 5-leaved pines (6). These necessarily depend for reliability upon the observer's complete and minute knowledge of the *Ribes* and pines within considerable areas. Hence, such observations are of very uncertain value. Investigations showing that the æciospores of this fungus are distributed for miles largely invalidate such observations so far as overwintering is concerned.

In North America, investigations of overwintering on *Ribes* plants have been along the following lines: (1) By means of spores adhering to dormant *Ribes* plants, (2) in dormant or partially opened *Ribes* buds, (3) in living *Ribes* leaves which themselves lived over winter, (4) on dead *Ribes* leaves, and (5) on infected *Ribes* stems.

Overwintering by means of spores adhering to dormant *Ribes* plants has been investigated in several ways. A great many field observations have been made upon bushes diseased heavily one year and not infected the succeeding year. Cases where bushes were shipped from known diseased localities and have shown the rust the next season in their new locations, have been considered, but the evidence has been too incomplete to be seriously considered except as it might help to confirm or refute other stronger evidence. A great many *Ribes* plants have been used by the writer in greenhouse experiments; they shed their leaves and become dormant for several months, yet there has been no hint of the carrying over of the fungus upon them from one season to the next. A cooperative experiment was made with Stewart (151), using 500 plants of *Ribes nigrum*, which in the summer of 1912 were heavily infected. The leaves dropped normally. They were then dug and most of them heeled in out of doors until February, 1913. They were then brought into greenhouses in six widely separated localities and allowed to put forth new leaves. Examination of some of these dormant plants by Arthur and Petry showed that plenty of urediniospores still adhered to the stems and buds. Inoculations with these spores did not give any infection, so that they presumably had lost their viability. The results reported by six different investigators showed no infection appearing on the new leaves.

Howitt and McCubbin (56) in attempting to solve the overwintering problem, made the following tests:

(1) In the fall of 1914, 16 black and 7 red currant bushes and 1 gooseberry bush, all badly rusted, were stripped of leaves and placed in cold storage, where they remained until March 16, 1915. At this date they were removed and planted in a greenhouse. All grew well and produced healthy leaves and fruit and were entirely free from rust throughout the summer. In addition, 17 black currant bushes, which had been badly rusted in 1914 and which were wintered in the field, were added to the above on April 21, 1915. These also grew normally and without rust.

(2) Seventy-eight black currant bushes, badly rusted in 1914 were wintered in the nursery rows, and transplanted April 12, in various gardens, isolated as far as possible from infected white pines and currants. These were inspected six times during the summer, the last inspection being made on October 2. At this date all were still free from rust except two bushes, on each of which a few rusted leaves were found. There is reason, however, to suspect that these infections might have been due to spores carried from currants about a mile distant from the garden in which they occurred. In no case was rust found on any of these currants which were located more than a mile from a source of infection.

(3) A number of bushes from the same source as No. 2 were planted in five lots in a region known from personal observation to have been entirely free from the rust in 1914, and which is 60 miles from the nearest known source of infection. Of the 100 bushes set out here only one developed rust, and this late in the season. All conceivable sources for this infection have been accounted for except two, viz, the wintering over of the rust on the currant itself, or accidental infection from spores carried on the writer's clothing while making an inspection on May 24.

In 1917, V. B. Stewart (152) tested the possible overwintering of the fungus by means of spores adhering to diseased bushes of *Ribes nigrum*. These were heavily infected in 1915 and 1916. In August, 1916, they were defoliated, and 200 were dug and placed in a storage cellar in October, where they remained all winter. In 1917, they were sent to Ithaca, N. Y., and set out in a field. The disease had not been known within 40 miles. The disease did not appear upon them up to October 9, 1917.

The possibility of overwintering in *Ribes* buds was brought to the writer's attention by infections of petioles (131, 134, 135), by which means it seemed entirely possible for the mycelium to travel from a leaf blade down the petiole and thence into the stem and bud in the axil of the leaf. While many diseased petioles have been examined, no indication of the migration of the hyphæ into the stem or bud has yet been seen. Direct examination of buds on heavily infected bushes has also failed to yield any indication of bud-scale infection (151). McCubbin (85) suggested but could not prove that infection of partially opened buds late in the fall might result in some of the infected leaflets surviving the winter and developing the disease the next spring. York⁵¹ successfully inoculated the inner bud scales of opening buds of *Ribes nigrum* with æciospores, suggesting overwintering in this way.

The possibility of green leaves living over winter on *Ribes* plants out of doors has been investigated. In three cases, the writer had *Ribes* plants growing in pots plunged in sand out of doors at Washington, D. C., retain green leaves through the winter until the spring weather of March, 1918, set in. One plant of Cumberland gooseberry and two plants of Utah Yellow currants did this. They were taken as specimens on March 22, when warmer weather set in. The

⁵¹ York, H. H. Op. cit.

previous winter a single seedling plant of an unknown species bore leaves flat on the soil under similar conditions until March 12, 1917, when it was brought into the greenhouse and inoculated. It promptly took the disease on the overwintered leaves. York⁵² found *Ribes glandulosum* plants in the spring of 1918 which bore overwintered leaves that later became infected naturally. In such cases, it would be easy to understand that late infections in the fall might lie dormant until spring and then produce vigorous uredinia. More time is necessary to determine whether this actually occurs.

As stated previously, infection of petioles by *Cronartium ribicola* is quite common. Early in 1917 Colley (17) discovered that infected petioles often had telia and masses of active mycelium as well as uredinia in the central pith. This raised the question of the possibility of such mycelium remaining active until spring and producing new uredinia.

Whether the fungus can live over winter on dead diseased leaves seemed unlikely in view of the negative results of Arthur and Petry (151) with urediniospores from stems of plants diseased the preceding summer, and the negative results of Stewart (151) with material overwintered out of doors at Geneva, N. Y. Howitt and McCubbin (56) early in 1915 attempted to produce infection by spores which remained over winter out of doors on dead *Ribes* leaves. All of their attempts were unsuccessful. In the spring of 1918 York (180) and the writer obtained infections with urediniospores overwintered out of doors in Massachusetts on dead *Ribes* leaves, proving that urediniospores may survive the winter. This was repeated in the spring of 1919 by Taylor (157).

The possibility of infection on *Ribes* stems was early investigated by the writer but with no success. Many inoculations were made on young *Ribes* shoots by the writer and later by Gravatt, Doran (28), and York⁵² but without success. However, in the summer of 1917, Posey and Gravatt (112) discovered fruiting uredinia on the young shoots of *Ribes hirtellum* at Kittery Point, Me. They inoculated other young shoots with æciospores and secured mature uredinia. Colley found uredinia in the pith of these infected stems. Gravatt later inoculated young seedlings of *Ribes fasciculatum* in the greenhouse with æciospores and secured heavy infection of the cotyledons. In one seedling the fungus also attacked the stem just below the diseased cotyledons and developed several uredinia (Pl. V, fig. 2). Later, however, the plant outgrew the disease. Taylor and York have successfully inoculated stems of several species of *Ribes*. (See p. 50.)

That *Cronartium ribicola* overwinters on *Ribes* is established.

⁵² York, H. H. Op. cit.

IMPORTANT DATES IN THE LIFE HISTORY OF *CRONARTIUM RIBICOLA*.

Table V shows some of the more important dates in the development of the white-pine blister rust and their variation according to locality. These dates are rarely the earliest or latest possible ones, but are based upon notes actually made respecting the point covered. It is hoped to extend this table greatly and approach nearer the actual date when each stage of development is reached by the fungus in the various regions. Southern New England is here made to include Massachusetts, Connecticut, and Rhode Island. Northern New York is understood to include approximately that part of the State lying north of a line between Glens Falls and Oswego. The Lake States include Michigan, Wisconsin, and Minnesota. Similar data for Europe are given in the last columns of the table for the sake of comparison.

TABLE V.—Important dates in the life history of *Cronartium ribicola*, as observed in America and in Europe.^a

[To economize space, the century digits 19 are omitted in noting the year of each observation; thus '09=1909.]

Development noted.	United States.					Europe.	
	Southern New England.	Southern New York, New Jersey, and eastern Pennsylvania.	Northern New England.	Northern New York.	Lake States.	Date.	Local-ity. ^b
First closed blisters.....	Apr. 7, '17	Apr. 30, '11	Apr. 15, '10	Apr. 26, '18	May 5, '17	Apr. 16, '90	H
	Apr. 5, '18	Apr. 28, '17	Apr. 7, '17	Apr. 21, '19	Apr. 19, '18	Apr. 15, '01	M
		May 4, '18	May 13, '18		Apr. 18, '19	Apr. 7, '09	D
						Mar. 17, '18	F
First open blisters.....	June 22, '09	June 1, '09	June 14, '09	June 8, '09	May 24, '16	Apr. 15, '90	H
	May 22, '11	July 27, '10	May 26, '10	May 12, '10	May 8, '17		Bo
	May 16, '12	May 5, '11	June 9, '11	Apr. 26, '18	Apr. 19, '18	Apr. 29, '96	S
	June 3, '13	June 10, '13	May 15, '12	Apr. 23, '19	Apr. 22, '19	Apr. 28, '08	B
	May 25, '14	May 20, '15	June 6, '13				
	June 2, '15	Apr. 7, '16	May 15, '15				
	May 3, '16	Apr. 28, '17	May 15, '16				
	Apr. 17, '17	May 16, '18	Apr. 29, '17				
	Apr. 7, '18		Apr. 23, '18				
	Mar. 28, '19		Apr. 7, '19				
Last yellow blisters.....			June 7, '10	June 12, '18	June 24, '17	May 15.....	H
			July 1, '17	June 26, '19	June 24, '19	May 9.....	D
			July 21, '18		Sept. 16, '19 ^c	June 1.....	Bo
						May 19, '18	F
First uredinia ...	June 3, '16	June 10, '13	July 24, '13	July 25, '09	June 9, '16	May 23.....	D
	June 13, '17	July 18, '16	July 14, '14	July 18, '16	June 12, '17	May 30.....	B
	May 29, '18		May 20, '17	June 28, '17	May 18, '18	May 26.....	B
			May 16, '18	May 16, '18	June 5, '19	June 2, '19	S
			May 23, '19	May 23, '19			
First telia	June 17, '16		June 26, '13	Aug. 23, '17	July 21, '16	Aug. 1.....	B
	July 21, '17		July 24, '16	June 26, '18	June 12, '17	July 30.....	M
	June 19, '18		June 10, '17	June 30, '19	July 8, '18		S
	July 30, '19		June 2, '18		July 10, '19		
First pycnia/ drops.....	June 21, '16		July 26, '13	July 3, '18		June.....	H
	June 7, '18		June 7, '18	June 26, '19			

^a Notations for Ontario, Canada: First open blisters—May 10, 1917, and June 22, 1918; first uredinia—June 24, 1915, and July 20, 1916; first telia—June 24, 1915.

^b Abbreviations used: B=Berlin, Bo=Bohemia, D=Denmark, F=France, H=Hamburg, M=Munich, S=Silesia.

^c This date is an extraordinarily late one for æcia to be formed, but it is included here to show the possibility of the æcial season being prolonged throughout the summer.

CONTROL OF THE WHITE-PINE BLISTER RUST.

Significant Factors Which Determine Control.

FACTORS IN THE FUNGUS.

The significant features in the life history of *Cronartium ribicola* are as follows: The pycnospores are apparently functionless; the æciospores are not known to infect pines, but they do infect *Ribes* readily; the urediniospores are not known to infect pines, but they do infect *Ribes*; the sporidia produced by the teliospores are not known to infect *Ribes*, but they do infect pines.

The spores are all distributed by the wind much more than by any other agency. The æciospores are carried and are capable of infecting *Ribes* leaves miles away from their source. The urediniospores are distributed a number of hundred yards, but appear to lose their viability soon, so that infection by them is rather limited in extent. The sporidia produced by the teliospores appear to be distributed to a distance of a few hundred yards, but they are so frail that they soon lose viability. Infection by them is limited to 100 to 600 yards as a general thing, and more commonly the former than the latter distance.

The fungus lives over winter most commonly by means of the mycelium, presumably in the needles and certainly in the bark of infected white pines. It occasionally overwinters by means of the æciospores in cankers of pine bark or by the urediniospores on *Ribes* leaves. The æciospores produced by the overwintered mycelium in the pine bark are the principal source of infection of the *Ribes* leaves each spring. The æciospores carry the disease far and wide for miles to the new *Ribes* leaves. The urediniospores intensify the disease in the vicinity where it is started by the æciospores. The sporidia carry the disease back to those pines which are relatively near infected *Ribes* bushes.

High humidity of the air is necessary for any of the spore forms to germinate and to produce infection.

FACTORS IN THE ENVIRONMENT.

CLIMATIC FACTORS.

Climate may be reduced to the three most potent factors—moisture, sunshine, and wind. *Cronartium ribicola* is absolutely dependent upon abundant moisture for its development. Drought, especially if prolonged, apparently may hinder the development of the æcia (49, 135). Lack of moisture prevents germination of all the different forms of spores. It prevents or very greatly reduces the extent of infection on *Ribes* plants by æciospores. It prevents the production of new generations of urediniospores,⁵³ and consequently prevents the abundant formation of uredinia as well as

⁵³ Pennington, L. H. Op. cit.

restricts the spread of this stage of the fungus. Moreover, drought very largely reduces viability of the urediniospores.⁵⁴ With the very short-lived sporidia of the teliospores it is evident that lack of moisture immediately after their production may entirely prevent their infecting pines at all, and drought is known greatly to limit their formation. Drought causes the premature fall of leaves of *Ribes* bushes so as to leave practically nothing for the fungus to subsist upon late in the season. Thus the crop of teliospores is so greatly reduced in times of drought that infection of pines is largely or entirely prevented. Drought kills many young *Ribes* seedlings and many are winterkilled (23, p. 8). On the other hand, rain undoubtedly beats down the spores floating in the air and washes spores from the host plants, so that infection by them is prevented.

Sunshine, by influencing the moisture of the air, may be very potent in reducing the activities of the fungus. It has a direct deleterious effect upon the spores⁵⁴ (30, 88). It is an open question whether the erratic germination of the urediniospores is not due to this action of the sun's rays. By promoting the quick maturity and hardening of the leaves of *Ribes* in the open, bright sunlight may greatly reduce the infection which develops upon them.

Wind is apparently the chief agent disseminating all forms of spores of this fungus. Its activity greatly influences the spread of the disease.

THE AGENCY OF MAN.

Man is a most potent agent in the dissemination of the white-pine blister rust. Through his activities it has made all of its known long-distance jumps. There is reason to believe that it is a native of northern Asia, whence it spread to Europe. The extensive trade in young trees of *Pinus strobus* is known to have been the means of introduction of this disease to many parts of Europe (111, 120, 155, 162, 170). It certainly came to North America in young white-pine stock from Europe and has attained its present wide distribution here in such imported stock. See figures 2 to 12, showing the progress of the disease since 1909.

INSECTS AND OTHER ANIMAL FACTORS.

Various animals (insects, snails, mammals, man, etc.) may aid in the distribution of the disease by carrying spores on their bodies, or they may retard or reduce the fruiting of the fungus by eating the sori on both pines and *Ribes*; and others such as gipsy-moth larvæ, other insects, snails, and squirrels may even eat the surrounding bark on pines, so that no more sori can form. (Pl. III.) In 1918, Pennington⁵⁴ estimated that the production of æciospores in the Adirondacks

⁵⁴ Pennington, L. H. Op. cit.

was reduced about 15 per cent by the eating of infected bark by mice, squirrels, porcupines, etc. Posey and Gravatt⁵⁵ found that squirrels had eaten 17 per cent of the æcia-bearing bark in a given area at Kittery Point, Me., and this is substantially true for the infected forests of that section. The leaf-eating insects and mammals may so reduce the leafage of *Ribes* plants as to reduce the disease materially in a given locality.

OTHER FUNGUS FACTORS.

Other fungi are of some importance also. At Kittery Point, Me., Colley (20) and Posey and Gravatt⁵⁵ found that secondary fungi work in the pine bark infected by *Cronartium ribicola* in such a way as nearly or entirely to kill out the latter, probably by killing the bark around the cankers so that the blister rust is starved out. This sort of thing is quite general where white pines are generally infected by *Cronartium ribicola*. Very often it appears that the diseased pines are killed finally by the secondary fungi rather than by the blister rust. The æcia of *Cronartium ribicola* are sometimes attacked directly by other fungi (80, 168, 172). It has also been found that the uredinia and telia are attacked by various fungi, so that their efficiency is greatly reduced locally (116). Fungi parasitic upon the leaves of *Ribes* sp., causing their premature fall, may greatly reduce the leafage available for the blister-rust fungus to attack and thus reduce the quantity of teliospores to produce infection on pines.

FACTORS IN THE HOSTS.

There are certain factors in the hosts themselves which are important in the control of this disease where it has once become established. These are resistance by some of the hosts to the disease and the natural suppression of the lower branches of white pines.

Among the white pines the blister rust attacks *Pinus strobus* with especial virulence. It does not attack *P. cembra* nearly so readily. Experience shows that *P. flexilis*⁵⁶ is decidedly susceptible to it. This is confirmed by Moir's studies in Sweden. Knowledge of the relative susceptibility of the pines is extremely limited, because the disease has been in North America too short a time and has not yet reached any but the eastern white pine. In Europe, where the older outbreaks have occurred, there undoubtedly is an opportunity to obtain definite data on the relative susceptibility of the pines. It may prove feasible ultimately to plant another species of white pine which is not nearly so susceptible to the blister rust and which also is of value as a timber tree.

⁵⁵ Posey, G. B., and Gravatt, G. F. Field studies on the white-pine blister rust at Kittery Point, Me. Seen in manuscript.

⁵⁶ Pennington, L. H., Snell, W. H., York, H. H., and Spaulding, P. Investigations of *Cronartium ribicola* in 1920. Seen in manuscript. Published in *Phytopathology*, v. 11, p. 170-172. 1921.

It has been possible to learn a little more concerning resistant species and varieties of *Ribes*. *Ribes alpinum* is found to be immune in America, although it is stated that it takes the blister rust in Europe. There does not appear to be any resistant species which will take the place of the cultivated *R. nigrum* (the black currant), or of *R. odoratum (aureum)* (the flowering currant). Among the cultivated red currants the varieties Franco-German, London, Rivers, and Holland have shown themselves very resistant. In generally infected areas these may prove of value to replace the more susceptible varieties.

In the outbreak area at Kittery Point, Me., one of the oldest in North America, the infected pines are thickly crowded together and mostly range in height from 15 feet upward. The lower branches are being suppressed and are dying rapidly from overcrowding. Experience has shown that trees and branches attacked by the blister rust are weaker than healthy ones and are more apt to die from drought and suppression. Posey and Gravatt⁵⁷ find that this natural suppression of lower branches at Kittery Point has resulted in the killing of many entire branches bearing blister-rust cankers well out from the trunk of the tree. In such cases the disease in the dead branches is killed also. They find that about 15 per cent of the trees originally infected have thus recovered from the disease before it reached their trunks. As above intimated, this process is probably at its height in this area, since suppression of the branches is apparently at its maximum.

Experiments in Control in Europe.

In experimenting with the white-pine blister rust, the European investigator has always had a different viewpoint from that of the investigator in North America. This has been due to two reasons—the disease was possibly native in Europe, certainly in Asia, but was introduced into North America; *Pinus strobus*, the favorite pine host for the fungus, is native in North America and introduced into Europe. That is, the situation is exactly reversed in every respect in North America as compared with Europe.

The disease is generally considered to have been native in the Alps and in the Ural Mountains upon *Pinus cembra*. It appeared in widely separated localities through Northern Europe before plant pathology had developed to any extent. That is, organized quarantines, present methods of spraying, and many other methods now used in fighting plant diseases were unknown at that time. The fact that the disease was prevalent practically throughout northern Europe before it became generally known, showed plainly that it was firmly established throughout that region. This meant that

⁵⁷ Posey, G. B., and Gravatt, G. F. Op. cit.

eradication was impossible. Local control has therefore been the only aim of the Europeans. Besides all this, the application of methods of control to plant diseases in Europe has never been developed to such a point as it has in North America except for relatively few diseases of the more important cultivated crops. There has apparently never been a well-planned investigation of the control of this disease extending over a number of years anywhere in Europe. All European publications upon control are fragmentary. It is evident that many scattered efforts have been made to control the disease there, but the results have never been published.

As stated above, the status of *Pinus strobus* in Europe is entirely different from its status in North America. While it has been more than 200 years since it was introduced into Europe (5), it of course has not approached the distribution that a tree does in its native region. It has been widely distributed in Europe as a park and ornamental tree and has been very popular for this purpose. As a forest tree it is a species which is planted in relatively small blocks and even then only on an experimental scale. In Europe it is essentially an ornamental tree rather than an important timber tree. Its total value there is exceedingly small compared to its total value in North America.

Legislation against plant diseases in Europe is so complicated that no attempt will be made here to give an outline of it. Incidentally, it should be stated that Tubeuf (162, 163, 164, 169, 170, 174) has repeatedly called attention to the fact that commercial nurseries have been and are still spreading this disease throughout Germany. In 1904 he (170) repeats earlier demands for a national control of the forest-tree nursery trade and goes so far as to refute the statements of Schwarz (125) that this disease in the nurseries at Halstenbek is absent or negligible. It is evident that the nursery trade dominated the situation and prevented such action.

Since the disease on *Ribes* plants is essentially one of the leaves, there has been an apparent chance for success by spraying them. Tubeuf (165) seems to have been the first to report on such tests. He sprayed *Ribes* leaves in the greenhouse with Bordeaux mixture and then set the sprayed plants among those already diseased. Numerous uredinia soon developed on the lower sides of the sprayed leaves. Jaczewski (58) says that spraying with Bordeaux mixture is not very effective.

Ewert (37) in 1912, to prove whether infection of *Ribes* leaves always occurs on the lower side only, made a test on a bush of *Ribes nigrum*. This bush was one of a number of *Ribes* plants upon which *Cronartium ribicola* had appeared every year for a decade. One-half of the bush was sprayed on the lower sides of the leaves only; the other half was untreated. Spraying was done on March 28, April 9

and 27, May 3, 7, and 20, June 1, and July 9. About 1,000 leaves were borne on the bush on June 27 so that each half had approximately 500 leaves. At that time the unsprayed half had about 250 leaves so heavily infected on the lower surface that some were already about to fall. On the sprayed half only 10 leaves were infected, all but one of these had only 1 or 2 sori, a single leaf had more. In this season the fungus attacked all the *Ribes* bushes very heavily, more so than for 10 years preceding.

It is noted that Ewert does not say specifically that sori formed only on the lower surface of the leaves. They may be presumed to have done so.

On April 26, 1913, Ewert placed four potted plants each of *Ribes nigrum*, *R. aureum*, and *R. rubrum* (var. Red Holland) around a tree of *Pinus strobus* heavily infected with *Cronartium ribicola*. On April 26, May 9, 17, and 24, June 6 and 21, and August 3, the several plants of each species were treated as follows:

Plant 1, sprayed with 1 per cent Bordeaux mixture on only the upper surfaces of the leaves.

Plant 2, sprayed with 1 per cent Bordeaux mixture on only the lower surfaces of the leaves.

Plant 3, sprayed with 1 per cent Bordeaux mixture on both surfaces of the leaves.

Plant 4, untreated check plant.

The checks on May 17 had two leaves with a considerable number of uredinia; on May 25 almost all leaves bore uredinia; and on July 28 there were 50 heavily infected leaves.

Plants numbered 1 (sprayed on the upper surfaces only) on May 25, showed the first uredinia on one leaf; on June 3 six leaves were infected, two very heavily; on July 28 there were 50 infected leaves.

Plants numbered 2 (sprayed on the lower surfaces only) on June 3 first showed very slight infection on two leaves; on July 28 four leaves were infected, all lightly.

Plants numbered 3 (sprayed on both upper and lower surfaces) on July 24 were healthy. On June 28 one leaf bore a single uredinium.

Here again Ewert fails to state definitely whether or not the infections were all on the lower surface of the leaves.

Ewert's experiment of 1912, spraying one-half of a *Ribes nigrum* bush, was repeated in 1913. In this case the sprayed leaves remained healthy, except where they were not thoroughly reached with the spray. This exception seems to the writer to be significant, as it indicates that spraying carefully enough to control the disease was apparently not practicable even for as painstaking an experimenter as Ewert showed himself to be in planning and carrying out these tests. In 1912 the disease was very virulent, while in 1913 it was not. This probably largely explains the better showing made in 1913 in these experiments. Although spraying greatly

reduced the number of uredinia, it did not entirely prevent their formation.

The spraying of pines with fungicides apparently has not received much attention. It is reported that the infection of young seedlings of white pine has been controlled by spraying in Belgium (106).

Pines have been treated in Europe by the application of various chemicals, but the following cases are the only ones where results are given.

Hostermann (55) treated the affected parts of two *Pinus strobus* trees with 10 per cent and 20 per cent solutions of carbolineum. This was applied with a brush on April 28, 1908, before the æcia matured, and again on May 12 and 18. The next spring, æcia started to develop, and the treatment was repeated with a 50 per cent solution of carbolineum. The tree was apparently unhurt, but in the spring of 1910 the fungus was still alive.

In another case (102), where 15-year-old trees were badly attacked on the trunk and the leaves had turned noticeably yellow, the bark was scraped off and the area bandaged with "carbolineum avenarius." A second tree was scraped and a 10 per cent solution of potassium permanganate applied. On a third tree a 1 per cent solution of copper sulphate was used. The first and second trees recovered and the last one died.

Büttner (9) treated 18-year-old *Pinus monticola* trees which had trunk infections. Attempts at cutting out the infections failed. He then applied "tree wax" to the visible infection itself and 20 cm. above and below it. The trees showed no blister rust in 1906. It would be interesting to learn if this held true for several years.

Eriksson (33) recommends the use of tar to cover the infections and prevent the distribution of the spores.

Tubeuf (164) says that valuable trees may be saved by cutting out infections and treating with lysol, asphalt, etc., if *Ribes* are removed for a distance of 50 meters, so that no new infection can occur.

Kneiff (74) removed blisters by frequent wet rubbing. He also used "tree wax" and cloths wet with carbolineum. These hindered the disease, but he says the best way to fight it is the removal and burning of the diseased parts or plants.

Pechon (105) advises burning affected trees and states that treatment with tar and similar substances will not suffice.

Köhler (75) tried cutting out and smearing, but gave up these methods as causing too much injury and even death. He sprayed the trunks with a strong stream of water before the blisters opened in the spring. The blisters disappeared and the trees formed new bark.

Fungi which parasitize *Cronartium ribicola* are not uncommon. Their use in artificial inoculation of infections on pines has been attempted (172, 173, 174), but with little success. There appears to be little prospect for success commensurate with the expense involved.

The separation of the pines from the *Ribes* plants is the most efficient method of controlling the disease in a given locality. To judge from the frequency of this recommendation for combating the disease in European literature, apparently considerable work of this kind has been done in Europe; but no definite statement of results in specific instances have been found.

The use of screens of another species of tree between *Ribes* and *Pinus strobus* has been recommended in Europe (131, p. 41). No one has stated the results of such treatment in any given instance, however.

There must be a chance to secure much valuable data on the success or failure of various methods of treatment which have been tested in Europe, but which have never been published. This can only be done by making definite investigations in Europe from the American standpoint. It must be remembered that from the European point of view the white pine is an introduced and comparatively unimportant tree. Its diseases, therefore, are not made the subject of systematic and prolonged study. Many facts of value fundamental to the control of this disease in America can only be determined by the intimate study on the ground of the much older infections of Europe.

Experiments in Control in North America.

In all control of parasitic plant diseases the fundamental thing is to determine the extent and the distribution of the disease to be controlled. The parasitic fungi are so generally distributed by the wind and are so insidious in their spread that they usually have gotten well started before their presence is discovered. Newly discovered imported diseases must be attacked at once or not at all, if eradication is to be accomplished, but more attention should be given to the matter of determining reliably the extent of outbreaks of such diseases. Scouting is a very important part of any disease eradication or control campaign. A well-conducted, intensive, plant-disease survey will do much to aid in determining the status of a new disease.

METHODS USED.

The control of white-pine blister rust has been attempted in North America (1) by means of quarantines of the host plants, (2) by the eradication of advance infections, (3) by the separation of the two hosts, (4) by sanitation, (5) by screening *Ribes* or pines

with other species, (6) by the judicious selection of planting sites for pines, and (7) by such minor methods as spraying, close pasturing of *Ribes*, and the removal of the diseased plants or parts of them.

QUARANTINE.

In North America (131, p. 54-55), Canada took the first official action against the white-pine blister rust, placing it on her list of proscribed plant diseases and later prohibiting the entry of all 5-leaved pines from

all other countries. Since then (2) a quarantine has been declared against the shipment of *Ribes* from points east of a line between Saskatchewan and Alberta to points west of that line. The shipment of *Ribes* to points west of this line is allowed from points in the United States south of the above protected area. These modifications are made to help protect the western white-pine area from the shipment of this disease in nursery stock, and to connect

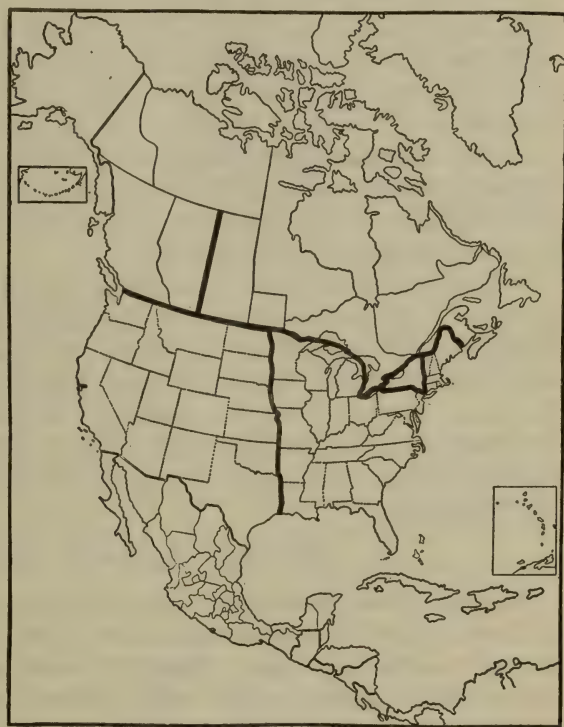


FIG. 13.—Outline map of North America, showing the quarantine lines established by the United States Department of Agriculture to control the white-pine blister rust by prohibiting the shipment of the host plants from infected territory to uninfected sections. The quarantine line established by Canada to prevent the shipment of diseased nursery stock across the prairie region from the eastern Provinces is also shown.

with this end in view (fig. 13). The United States Government in 1912 (94) put in force a regulatory act controlling the entry and movement of nursery stock. This act prohibits the entry of 5-leaved pines and of *Ribes* from Europe, Asia, and Canada; forbids the shipment of such stock from the eastern section of the country to points west of the western boundaries of the States of Minnesota, Iowa, Missouri, Arkansas, and Louisiana; and also forbids the

shipment of 5-leaved pines and of *Ribes nigrum* from the States of New England to any of the other States and from New York to points outside that State. Still more recently, an absolute embargo has been placed on ornamental and forest tree and shrub stock from other countries (fig. 13).

These quarantines prevent our getting more of the white-pine blister rust from other countries. The Great Plains region forms a natural barrier (fig. 13) against the spread of this disease from the East to the West (97, 98, 141, p. 7; 148)). Since it is already well distributed and established east of this barrier, the immensely valuable western white pines can be protected very efficiently by preventing the shipment of white pines and *Ribes* from the infected section to the western region, which is still free from the disease. This is accomplished by quarantine, which is designed to prevent the shipment of infected stock from a generally infected district to those States which are not generally infected and to exclude plant pests from all the rest of the world (98).

Within the past four years many of the various States have enforced regulatory measures with reference to this disease (94). These States are California, Delaware, Georgia, Idaho, Illinois, Indiana, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nevada, New Hampshire, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Vermont, Washington, West Virginia, and Wisconsin.

ERADICATION OF ADVANCE INFECTIONS.

In 1909, when *Cronartium ribicola* was first found upon white pines in North America, it appeared to occur only on recent shipments of young trees from Europe. That is, it was present in advance infections, and so far as could be determined there was no generally infected area. Since that time areas have been found which are generally infected, and we have both types of infections to reckon with. (See figs. 2 to 12.) Where advance infections were small it appeared to be feasible to attempt eradication of the disease, but when generally infected areas were found eradication became impossible, and local control was the only feasible thing to be attempted.

When this disease was first discovered on *Ribes* in 1906 at the Agricultural Experiment Station at Geneva, N. Y., an attempt was very properly made to eradicate the disease. All of the *Ribes* in the infected plat were destroyed. Very few white pines were within half a mile, and none of these were found diseased. Stewart (150) published an excellent account of this case. It was not then known that the æciospores readily blow for miles in a viable condition, nor was that fact established until rather recently (128, 145, 146).

In 1909 it was learned that great quantities of infected young white pines had been imported from Europe in 1907, 1908, and 1909. (Fig. 1.) With conditions as they appeared to be, it was believed that eradication might be possible, and this was attempted. The disease was held in check in such shipments of diseased trees as could be located. But many could not be located. Moreover, for years before, as was subsequently learned, nurserymen and private individuals had imported from Europe many infected white pines. These we had no means of knowing about until too late, since the importers and planters did not inform us concerning them, even after the publication of warnings against the disease. Such diseased importations have been the centers from which most of our large outbreaks have started. So far as we can learn no Federal agency has imported white pines upon which this disease has been found.

More complete knowledge of the life history of the fungus has shown that it is impossible to eradicate it where both *Ribes* and white pines are native and abundant, after the æciospores are once set free in quantity. If both pines and *Ribes* be removed from a given area the disease may be eradicated in that area but it will have escaped beyond that area by means of the æciospores. This happened in Minnesota and Wisconsin, where all the white pines and *Ribes* were removed from large infected areas.

The removal of pines has been accomplished in a few cases. Entire plantings of imported pine stock were destroyed soon after they were found to be diseased, and in these cases *Ribes* were also removed or were absent from the area treated. The forestry officials of the State of New York took the lead in this work, destroying 1,200,000 imported trees in their nurseries in 1910 and 1911. A number of plantations were also destroyed in New York, New Jersey, and Vermont (131, 139). As early as 1912, the total destruction of diseased lots of imported white pines (133) was urged rather than weeding out only those which were visibly diseased. Public opinion would not permit this to be done in the wholesale manner that was necessary for efficiency. Yet this was the one efficient manner of handling such imported trees (136) before generally infected areas had developed.

SEPARATION OF THE TWO HOSTS.

The fact that each form of spore will infect but one of the hosts, at once indicates that a separation of these hosts will prevent the further progress of the parasite within the control area. If the pines only are removed, the disease will be likely to die out on the *Ribes*, since it apparently overwinters on them only infrequently; if the *Ribes* are removed, the disease is isolated on that particular lot of pines, where it overwinters (if the diseased trees are not also found and removed) and produces new crops of æciospores each spring. The

disease is kept from attacking more pines within the area where the Ribes are removed, but it may spread to Ribes miles away, there to start new pine infections, each of which will act as a new center of infection in future years. This makes it practically impossible where both white pines and Ribes are native entirely to eradicate the disease after the æciospores are once set free.

REMOVAL OF PINES.

In all work where pines have been removed the Ribes have been absent or were also removed; hence, all this work is placed under "Eradication of advance infections." In some of the States, Ribes-growing sections are being established, and it is expected that white pines will be entirely removed from such areas.

REMOVAL OF RIBES.

Experiments on a large scale are in progress in all of the States of New England and in New York, Wisconsin, and Minnesota for the removal of all Ribes in certain areas, to determine whether it is practicable thus to protect valuable white-pine stands.

Much work of this sort has been carried on during the past four years. Infected areas have been chosen and the Ribes removed under various conditions to show what possibilities there are in such work (23, 24, 25, 103, 104). The removal of all Ribes plants in a given area is a difficult matter. Wild Ribes offer the greatest difficulties. It is not humanly possible to find every plant in wild woodland; plants pulled up, if left touching the soil, may again take root and persist in a living condition; pieces of root crown and occasional pieces of roots left in the soil sprout and make new plants (23, p. 8); fruits on the pulled bushes fall off and start a crop of seedlings to replace the parent plant; seeds of old fruits already on the ground may germinate and start seedlings. Nevertheless, the results of this work are encouraging. Wild currants and gooseberries do not reproduce rapidly in an area that has been worked by an efficient crew. Thorough checking on 2,485 acres in 8 separate tracts previously gone over by eradication crews showed that on an average acre, 62 bushes (95.5 per cent) were destroyed in the first working and 3 bushes in the second working. Of the latter, two bushes were missed in the first working and one bush developed from seeds or sprouts. The remaining plants are so small that they carry but 1 to 2 per cent of the total Ribes leafage (24). Moreover, they are usually so low or so covered with other vegetation that very few become infected, so that the work results in almost perfect control of the disease. To judge from data at hand, control areas usually should be reworked within 10 years after the first working (25).

Two principal methods of removing Ribes have been developed. Where Ribes are abundant the Ribes eradication crew has to cover

all the ground and pull the Ribes as they go. Where Ribes are relatively scarce they are likely to occur only in certain favorable locations. In such territory an expert scout covers the ground, mapping it and indicating the Ribes areas to be worked by the crew. In favorable localities this has proved successful and greatly reduces the cost of Ribes eradication (25). Experiments in the killing of thick stands of wild Ribes with chemicals indicate that this method (113) materially reduces the cost.

Ribes eradication was started as early as 1909, but at that time was limited to plantations of infected imported white pines and to a safety belt of 100 yards around them. In 1910, the width of the safety belt was increased in some of the States to 500 feet, and in 1915 in Massachusetts to 500 yards. In 1916, 600 yards was taken as the safe width for all situations. Prior to 1919, facts concerning the spread of *Cronartium ribicola* from Ribes to pines were not definitely known. As a result of the investigations of the germination and dissemination of the sporidia the width of the Ribes-free zone was set, in 1919, at 200 to 300 yards for average conditions (25, 146).

In 1917, when extensive areas were first cleared of all Ribes, lack of experience in such work by all connected with the work greatly reduced its efficiency, but even then it was found that the outlook was not hopeless, although the cost of eradication of Ribes was too high to be justified except where pine stands were valuable. Efficiency has been steadily increased since then until it has been found that men green in this work can be quickly taught to find and destroy at least 95 per cent of all wild Ribes plants the first time over the ground (24, 25). A system of checking the work has been developed, as well as a system of accounts, so that present results are quite accurately known.

The cost of Ribes eradication has been steadily reduced. In 1918, 105,977 acres were worked in New England at a labor cost of 44 cents per acre. In New England and New York the average cost per acre including supervision in 1918, was 66 cents. In 1919, in New York and New England, 252,114 acres were worked at an average cost per acre of 54 cents, including supervision, and of 42 cents for actual labor (24, 25). Improved methods are expected to reduce still further this cost as, in New England alone, the cost in 1919 was 24 cents per acre, owing to the use of improved methods (24).

The efficiency of Ribes eradication with respect to pine infection will become evident as time elapses. Examination of areas where Ribes were eradicated in 1916 and 1917 has shown no new pine infections. This is in spite of the considerable number of Ribes missed in the early work.

The experiments in the removal of *Ribes* on an extensive scale have gone far enough to prove that it is a practical method of protecting pine stands. Accordingly the public has been urged to destroy wild and cultivated *Ribes* within at least 200 yards of valuable pine stands in the generally infected regions.

Assistance to individual pine owners, towns, and associations in protecting pine areas from the blister rust is given by the New England States, New York, Wisconsin, and Minnesota, in cooperation with the United States Department of Agriculture. In 1919, about \$10,000 was subscribed for cooperative eradication of currants and gooseberries by individuals and associations in New York. In Massachusetts, local co-operators furnished \$1,075. In New Hampshire, 53 towns voted appropriations totaling \$8,514, and 34 individuals and firms subscribed \$2,053 additional. The interest of the public in blister-rust control is further evidenced by the fact that this State destroyed 21,171 bushes of cultivated currants and gooseberries belonging to 1,023 owners, and only 3 owners insisted on compensation for their bushes (24).

The State and Federal authorities favor cooperation with towns, counties, associations, or groups of individuals in order to free from *Ribes* as large an area as possible in each locality. This reduces cost per acre and increases the effectiveness of the protection to pines.

SCREENING RIBES AND PINES WITH OTHER SPECIES.

Screens of heavy underbrush or trees surrounding or covering *Ribes* will do much to prevent infection of the *Ribes* by æciospores and will greatly reduce infection of white pines, if the *Ribes* do become infected (145, 146).

Screens or windbreaks of other kinds of trees around the edge of white-pine stands will greatly reduce infection on the pines. In the same way, planting in mixture or in strips alternating with another species should help to keep the disease down.

SELECTION OF SITES FOR PINES.

Infection by *Cronartium ribicola* may be reduced to a minimum in a generally infected area by judiciously choosing a site for the planting or natural seeding of white pines. Areas where there is a minimum number of *Ribes*, or where they have been eradicated, which are not in moist locations and are not especially subject to fogs or mists, and which are protected by forests or conformations of the land from heavy sweeping winds, are favorable for the encouragement of the growth of white pines. The converse conditions are to be avoided as far as possible.

SPRAYING.

Spraying has been little used in North America to control the white-pine blister rust, as the chances for success have appeared to be slight. Spraying of *Ribes* to prevent their infection has been tested in a number of instances.

In 1915, McCubbin (86) carried on some careful spraying tests with *Ribes nigrum* plants, using both Bordeaux mixture and soluble sul-

phur in parallel experiments. The following statement has reference to spraying that was done every two weeks through the summer:

It was realized that the spray would have to be applied to the under sides of the leaves to be effective, and though this was done as thoroughly as possible in our work, it must be admitted that it takes so much time and care that satisfactory spraying of this kind would be out of the question in a commercial way. Owing to frequent rains during the summer, the best results were not obtained from this work, but even allowing for this it was certain that, though the rust can be greatly reduced by spraying, it can not be controlled sufficiently to prevent the spread of infection. Consequently, whatever value spraying methods may have as a means of protecting individual plantations, they are likely to be of little use in combating the disease as a national pest. In this connection, it has been suggested by the Dominion Botanist that since spraying will not completely control the rust, it may work a positive harm by keeping the infected leaves longer on the bushes in the fall, and thus materially extend the period during which infection of the pine may take place, providing, of course, that the infection of pines is possible throughout the whole season.

Stoddard, in 1918 (23), carried out a spraying test in Connecticut, with the following results:

Spraying experiments for the control of the blister rust were conducted on red and black currants. Results were nearly negative on red currants because of lack of infection. On black currants spraying gave nearly complete control throughout the season. However, such careful and frequent spraying had to be done that it is not considered to be a practical method of control.

No experiments have been made in the spraying of pines, as it has appeared useless in larger trees where the infections have occurred. Seedlings in seed beds of nurseries may perhaps be protected from infection by spraying, as has been suggested by Clinton and McCormick (14). It should be well tested under extreme conditions (106).

CLOSE PASTURING OF RIBES.

The use of animals to feed on the leaves of *Ribes* is feasible if the area is pastured heavily until well cleaned up. Sheep are very close feeders and undoubtedly can be thus utilized (23, p. 7). Goats are the most promising animals for the purpose, however, as they are omnivorous feeders. This method can be recommended only for areas where small pines are absent or too few to be of value.

REMOVAL OF DISEASED PARTS AND DISEASED PLANTS OF RIBES.

The removal of the infected leaves has been attempted in a few lots of *Ribes nigrum* in nurseries, but it is costly and merely palliative in that it is usually only postponing more drastic measures. The cutting back of infected *Ribes* bushes has been tested in a few instances, but like the plucking of the leaves, it is usually unsatisfactory, since the bush remains to take infection another season.

The removal of diseased plants only of *Ribes* is unsatisfactory, as it has been found that it requires repeated visits through the season for the removal of plants which have developed the disease since

previous inspections. This makes the cost of the work prohibitive, and the disease progresses in spite of it.

REMOVAL OF DISEASED PARTS AND DISEASED PLANTS OF PINES.

The removal of diseased parts of infected pines does not appear to be an economical procedure from the viewpoint of the lumberman or wood-lot owner, because of the low value of single trees. For highly valued ornamental trees it becomes possible financially. Under such conditions, the removal of all *Ribes* to prevent new infection, accompanied by careful cutting out of all infections in the pines for several years, will finally result in the elimination of the disease from those trees. Martin, Gravatt, and Posey⁵⁸ have investigated the possibilities of this type of work. They conclude that—

Experimental and practical results show that ornamental pines which have already become diseased can be saved by cutting out the infected parts if treatment is applied in time. The work is easily performed at a comparatively low cost. Treatment can be given any time during the year, but best results will be obtained from April to June when the cankers are more easily found because of the bright orange-yellow blisters. Successful treatment depends primarily upon ability to find the cankers and determine accurately the edge of the diseased area. The workmen should be thoroughly familiar with the symptoms and appearance of the disease on pines.

Where the *Ribes* can not be thus eradicated, other species of trees should be planted to take the place of the white pines. Cutting out infections depends, for success, on finding all of them. The workman must be familiar with the blister rust and be thorough or the results will not justify the cost. If a tree is nearly girdled near the ground, or if most of the branches must be removed, it is useless to attempt to save it. The cutting out must be repeated for several years after all the *Ribes* are eradicated, as dormant and slightly developed infections become visible. Cutting out experiments showed that cutting back for $1\frac{1}{2}$ inches or more from the extreme edge of the infected area insured removal of all diseased bark and stopped the disease in those areas. In practice this distance should be increased to 5 or 6 inches to insure thorough work.

On a main trunk an infection which has extended only part way around the trunk may be treated by peeling off the bark on the canker and to the required distance around it. In this case the safety zone should extend for 4 or 5 inches directly above and below the diseased area but need not extend more than half as far sidewise.

The removal of only diseased white pines in infected imported trees has been inefficient and costly, even where the *Ribes* were removed too. Records of such work in about 900,000 imported trees (136) shows that it is inefficient, although the disease has been checked somewhat. The cost has been great enough to have replaced the imported trees with healthy home-grown ones.

⁵⁸ Martin, J. F., Gravatt, G. F., and Posey, G. B. Treatment of ornamental white pines infected with blister rust. U. S. Dept. Agr. Cir. 177, 20 p., 12 fig. 1921. Seen in manuscript.

In a region where *Ribes* are rare or practically absent the removal of the diseased pines only may serve to prevent progress of the disease. This allows the dispersal of æciospores and may result in scattering infection on *Ribes* miles away. In such cases it will take a long time to detect the escape of the fungus. In areas free from the *Ribes* the aim should be eradication rather than control of the disease, as such areas are the very ones where white pines should be grown in the future.

In generally infected districts where *Ribes* are removed for some distance, it may pay to cut out the worst infected trees to reduce the crop of æciospores and thus reduce infection around the borders of the treated area.

Status of the Control of White-Pine Blister Rust.

The present status of the control of the white-pine blister rust in North America may be summed up as follows:

Eradication of *Cronartium ribicola* is impossible except in small, isolated, advance infections. It should be attempted only in localities where the disease is quite limited in distribution and well separated from the known generally infected areas shown in figure 2. As a national problem, control is the only feasible thing. Protection of uninfected or sparsely infected areas by enforcement of the present Federal quarantines is necessary, since this disease is distributed to great distances only by means of infected nursery stock. The western forests of white pines can be protected from the blister rust for an indefinite period by rigid enforcement of the Mississippi Valley quarantine. A single diseased shipment may undo all attempts to restrict it to the eastern forests.

In the eastern forests blister-rust infection on *Pinus strobus* is rapidly developing. A strip survey in one locality in New Hampshire (24) shows that one-fourth of the white pines on an area of 72 square miles are now infected. The areas marked as generally infected in figure 2 show the great increase in general pine infection. Much of this infection will become visible in the next three years. It is an insidious disease, a tree not being noticed as diseased until it is heavily infected. There is abundant evidence that it is destructive to merchantable trees as well as to younger ones. It is just getting under headway.

Ribes nigrum is far the most dangerous species, but all *Ribes* are dangerous to white pines in generally infected areas. In such areas the disease can be controlled by the removal of all *Ribes*. Local control depends on the removal of *Ribes* within white-pine areas and the education of the white-pine owners to remove *Ribes* as a routine part of white-pine forest management. Local control by the removal of *Ribes* can be taken up at any time in the future, but if the present stand of trees is to be saved action must be taken at once.

A few years delay will mean serious loss. It is a simple and practical precaution to destroy the currant and gooseberry bushes before they destroy the pines. The demonstrated effectiveness of this method of control justifies pine owners in uprooting currant and gooseberry bushes on a large scale (24).

Those who do not do this in their pine lands and for a distance of 200 to 300 yards outside will be likely to see a valuable asset turned into a liability. In areas where the white pine is an important tree cultivated *Ribes* should not be planted. A number of States already have laws prohibiting such planting without permission from the State authorities except in areas designated and set apart as "currant-growing districts."

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THE CONTROL OF SAP-STAIN, MOLD, AND INCIP- IENT DECAY IN GREEN WOOD, WITH SPECIAL REFERENCE TO VEHICLE STOCK.¹

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(In cooperation with the Forest Products Laboratory of the United States Forest Service, Madison, Wis.)

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INTRODUCTION.

During periods of transit and storage, previous to its ultimate manufacture, green timber containing a high percentage of sapwood often suffers considerable damage. This is particularly true during the late spring and summer months when deterioration brought about mainly through a discoloration of the sapwood, known as sap-stain, sometimes necessitates degrading on a large scale. This staining of timber has occasioned severe losses in Europe as well as in the United States, and many expensive investigations have been made to determine the nature of the stain and to discover a satisfactory remedy.

¹The writer wishes to acknowledge his indebtedness to Mr. C. J. Humphrey, in charge of the Laboratory of Forest Pathology, Bureau of Plant Industry, in cooperation with the Forest Products Laboratory, Madison, Wis., for facilities and for advice in outlining the work; to Dr. Charles Thom and Miss Margaret B. Church, of the Bureau of Chemistry, for the identification of mold fungi; to Mr. H. D. Tiemann, physicist and specialist in kiln drying, Forest Products Laboratory, Madison, Wis., for the loan of photographs; to Mr. Joseph Ashcroft, of Poplar Bluff, Mo., for cooperation in the experimental dipping of spokes; and to all others who, by information, suggestion, or criticism, have contributed to the preparation of the manuscript of this bulletin.

The molding of green timber has frequently been confused with sap-stain as well as with incipient decay. However, in so far as the production of permanent stain or the effect upon the durability of the wood is concerned, molding is of comparatively little importance. Incipient decay caused by true wood-destroying fungi, on the other hand, is of great importance.

Early in the year 1918 the attention of the Office of Investigations in Forest Pathology was called to staining and molding occurring in green raw material by the wood-stock committee representing the National Implement and Vehicle Association and other vehicle and vehicle parts manufacturers through the Forest Products Laboratory of the United States Forest Service, Madison, Wis. The present investigation arose in connection with raw hardwood stock used in the manufacture of escort wagons and artillery carriages. A large quantity of this material was at that time being sawed or turned, largely from green instead of seasoned stock and shipped green from the saw. In some cases it was found necessary to cull severely such stock at destination, owing to the presence of mold, stain, or incipient decay which had developed during transit and while in storage. In cooperation with the Forest Products Laboratory and the wood-stock committee, a questionnaire² was sent to a number of the contractors for Army vehicles and parts and to producers of wood stock. Personal investigations were also made of the conditions existing at 45 mills and factories engaged in the sawing of timber, dimension stock, and veneer, or in the manufacture of airplanes, furniture, flooring, handles, vehicles, and vehicle parts. Most of these mills were located in the central and southern portions of the United States and were directly concerned in the production of war material. The object of both questionnaire and personal investigations was to gain information concerning the general sanitary conditions existing in the woods, railway cars, sheds, warehouses, and kilns; the details of manufacture of many vehicle parts; the extent of deterioration occurring in green raw material; the financial losses occasioned thereby; and, particularly, any practical methods of handling green wood stock that would prevent the development of stain and mold therein.

The investigations showed that many of the firms had experienced considerable pecuniary losses, which were due to the necessity of using a high percentage of green stock; to a shortage of cars, resulting in the congestion of material in the woods and railroad

² National Implement and Vehicle Association and other Vehicle and Vehicle Parts Manufacturers. Information Division of the Wagon and Vehicle Committee and the Wheel Manufacturers' War Service Committee. Wood Stock Committee. Sap-stain and mold in green lumber. Nat. Implement and Vehicle Assoc., etc., Bul. 24, 2 p., 1 fig. 1918. A. B. Thielens, chairman. Multigraphed.

yards; to lack of time for the proper air seasoning or kiln drying preparatory to shipment; and, finally, in some cases to a failure to understand the conditions necessary to safeguard the stock while in storage or in transit. Many of these losses due to emergency will be considerably reduced upon return to normal conditions.

Some manufacturers consider it important that, in order to overcome losses due to checking, certain kinds of stock produced at many of the smaller mills be shipped to them in a green rather than in a partly seasoned condition. They claim that these mills, not being equipped for the proper drying of stock preliminary to shipment, make it necessary for the manufacturer to insist that material from such sources be shipped in a green condition to the factory, where suitable means for storage and drying are maintained. Close attention must be paid to the handling of this material in transit or in storage if deterioration due to fungi is to be prevented.

The necessity for a careful conservation of timber in the United State is becoming more and more apparent (53,³ 54⁴). Measures, then, that will assist in preventing or reducing losses due to fungous attacks are of importance.

This bulletin presents a brief review of our knowledge of sap-stain and mold, a consideration of the causal organisms responsible for such deterioration in green wood stock, the results of the new investigations, and finally a summary of some of the important methods of control.

SAP-STAIN.

The "bluing," or sap-stain, of pine timber has been observed in Europe for many years. Both Hartig (17, 18) and Frank (11) refer to it in their investigations of plant diseases. Rudeloff (36) studied the effect of blue stain on the strength of pine wood. Münch (31) not only examined the properties of blued coniferous wood but also investigated the causal organisms and determined the optimum conditions for their development in the wood. In the United States considerable attention has been given to the subject by such investigators as Von Schrenk (41, 42, 43), Hedgcock (19, 20), Rumbold (37, 38), Weiss and Barnum (56, 57), and Bailey (5). Many of the investigations have been made in connection with the sap-stain of hardwoods as well as conifers.

³ The serial numbers (*italic*) in parentheses refer to "Literature cited" at the end of this bulletin.

⁴ These two reports on Senate Resolution No. 311 by the Forest Service of the United States Department of Agriculture may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 25 cents and 5 cents, respectively, per copy.

DEFINITION OF SAP-STAIN.

The term "sap-stain" refers to the blue, green, brown, or red discoloration which often may be observed in the sapwood of timber derived from several kinds of broad-leaved and coniferous trees. It must not be confused, however, with the superficial discolorations produced mechanically, i. e., by collections of dirt and coal dust, by deposits from the drip in leaky cars and sheds, or from the condensed moisture in kilns. Such deposits may occur upon heartwood as well as sapwood. Neither should it be confused with the common blue-purple stain apparent when rusty saws are used on certain green wood, such as oak. This stain results from the reaction between the tannic acids of the wood and the iron compounds from the saw. Finally, it must not be confounded with the variously colored superficial growths of molds or the more or less deep seated sap-rot, with its brown to bleached appearance and its tendency to produce a punky consistency of the sapwood itself.

There are two quite generally recognized classes of sap-stain: (1) The chemical stain, said to be produced by chemical reactions brought about through the agency of certain oxidizing enzymes present in the wood itself; and (2) fungous stains known to be caused by several species of fungi.

CHEMICAL STAINS.

Chemical stains due to enzymes cause discolorations in both the sapwood and the heartwood of sugar pine and hard maple (Tiemann, 51, p. 185; also Pratt, 34, p. 305-307). Such stains develop during air drying, particularly under warm and humid conditions, or in the kiln, and give more or less permanent discolorations to the wood, to wit, a brown stain in sugar pine (fig. 1) and a cherry color in hard maple. These defects cause degrading (34) and often result in financial losses. According to Bailey (5), when freshly cut sapwood of alder, birch, cherry, or red gum is exposed to the air during extremely warm and humid weather, chemical reactions often take place and within a few hours produce colored substances in the wood. Bailey (5) states that the microscopic examination of sections of such wood indicates that the colored substance develops particularly within the pith rays and the parenchyma cells. He states that certain soluble enzymes which assist in the oxidation of organic compounds and are of prime importance in the nutrition and growth of living organisms are widely distributed in plants and animals and may also produce post-mortem discolorations of certain organic compounds (see also Clark 8, 9). Yoshida (59) discovered in 1883 that an oxidizing ferment is responsible for the oxidation of the latex in certain species of *Rhus* and the formation thereby of black varnish, or lacquer. Investigations have also shown that discolorations in fruit juices,

vegetables, cereals, mushrooms, and various soft plant tissues are brought about through the agency of certain oxidizing ferments, the oxidases and the peroxidases (Asō 1, 2, 3; Clark, 8, 9; Kastle, 27). These ferments are sometimes distinguished by the production of a strong blue color in a tincture of guaiacum when used in the presence of oxygen or hydrogen peroxid (Haas and Hill, 16, p. 383). Bailey (5) states that the activity of these oxidizing enzymes increases with the rise in temperature to a certain point, which may be called the optimum, and then decreases as the temperature is raised above this point. In almost every case, according to the same authority, the activity is entirely destroyed before a temperature of 100° C. (212° F.) is reached. He also states that the activity of these oxidizing ferments is diminished or destroyed by certain antiseptics and by other chemical substances. According to Asō (1, 2), such substances as tannin, sodium fluorid, and sodium silicofluorid, interfere with the color reactions normally produced by oxidases. Bailey (5) notes the strong similarity existing between the oxidizing activities of these enzymes and the chemical reactions responsible for certain kinds of sap-stain, namely, post-mortem oxidation with change of color produced by solutions in contact with the air and the similar variations in the activity of the discoloring agency in relation to variations in temperature.

If discolorations in sapwood are due to the activity of oxidizing enzymes, which, as has been shown, are rendered inactive by exposure to a temperature of 100° C. (212° F.), a logical prophylactic measure would be the submersion of timber in boiling water. Bailey (5), during the spring of 1910, performed certain dipping experiments.

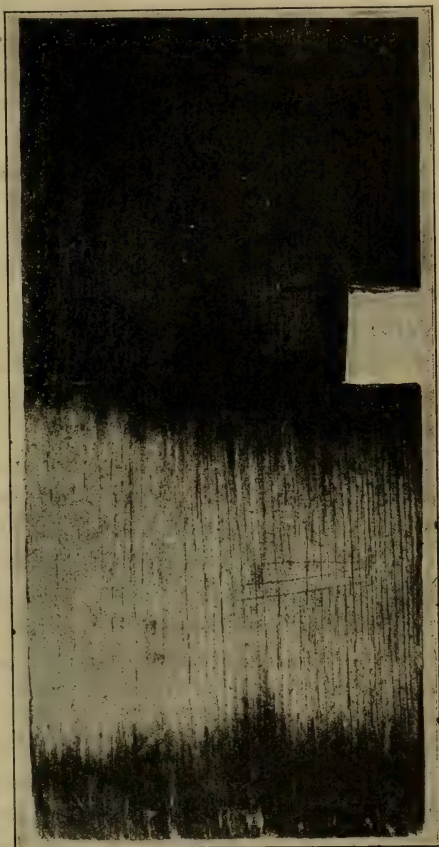


FIG. 1.—Board of sugar pine, showing chemical stain. The unstained area in the lower half of the illustration indicates the position of a crosser during the kiln treatment. The crosser afforded protection from oxidation. Photographed by H. D. Tiemann.

He found that when 1 by 3 by 6 inch boards of alder (*Alnus incana* Moench), white or gray birch (*Betula populifolia* Marsh), paper birch (*Betula papyrifera* Marsh), and various trees belonging to the rose family (Rosaceæ) were immersed in boiling water and then stacked under cover they would remain unchanged in color. Those boards which had been immersed in the boiling water and then placed in the most unfavorable conditions of high humidity and temperature in the open and exposed to the direct rays of the sun scorched on the surface. With the exception of this superficial scorching, no discoloration of the wood took place. On the other hand, untreated boards that had been cut from the same portion of the tree and subjected to similar conditions of temperature and humidity stained rapidly. Bailey (5) found that the rapidity and the depth to which the stain penetrates the wood varies with the temperature and the moisture, hot and humid weather being especially favorable for the production of stain. From a consideration of the results obtained, he concludes that sap-stain caused by oxidizing enzymes can be readily prevented by dipping the timber for a few minutes in boiling water.

Though chemical stains give more or less trouble in kiln-dried maple flooring and sugar-pine lumber, the discolorations may be prevented to an extent by the use of comparatively low temperatures (120° to 125° F.) and correspondingly low humidities (50 to 70 per cent; Tiemann, 51, p. 185). Because of their limited distribution and the fact that they do not impair the strength or durability of the timber, chemical stains in general can hardly be considered as having very great economic importance.

FUNGUS STAINS.

The second class of stains is produced by fungi. These fungi are disseminated by means of minute bodies known as spores. The spores may be produced in countless numbers and are blown about by the wind, washed along by the rain, or carried by animals, particularly insects. When, under favorable humidity and temperature conditions, they happen to lodge upon a substratum, such as the moist green sapwood of woods that contain the requisite food material, the spores may germinate and give rise to a mass of fine, usually septate threads, sometimes colorless at first, but often becoming darkened with age. This vegetative portion of the fungus is known as the mycelium, and the individual threads are called hyphæ. In some cases the hyphæ probably penetrate the wood but little, growing for the most part over the surface; in others, they may enter the sapwood through the medullary or pith rays. This does not result in the disintegration of the walls of the wood cells to any appreciable

extent. The starches, sugars, and oils stored in the sapwood and pith rays, together with the contained air and water, probably exert an influence upon the advancing hyphæ and limit largely the growth of the fungus to the sapwood and the pith rays, where the sap-stain is mainly to be found. Practically no invasion of the heartwood takes place (Von Schrenk, 41, p. 19). (Pl. I, fig. 3.)

THE SAP-STAIN FUNGI.

The relation of a fungus to the bluing of wood was first noted by Hartig (17, 18). He describes the organism which causes the so-called "bluing" of conifers, especially dead or dying pine that has been injured by caterpillars, as *Ceratostoma piliferum*. He notes that it may also appear in damp firewood. According to Hartig, the brown mycelium very quickly penetrates the trunk through the medullary rays. He states that probably on account of the deficiency in moisture content the heartwood is avoided by the mycelium, whereas the sapwood often becomes quickly invaded and decomposed. Although described by Fries (13; see also Berkeley, 6), who placed it in the genus *Sphaeria*, the fungus was later transferred by Fückel (14; see also Ellis and Everhart, 10) to the genus *Ceratostoma*. Saccardo (39) still later divided the genus *Ceratostoma* and placed those species which possess colorless spores in a new genus, *Ceratostomella*. Winter (58), in a subsequent revision of the family included the fungus as *Ceratostomella pilifera* Fries under the new genus. It is now known as *Ceratostomella pilifera* (Fries) Winter (Engler and Prantl, 29).

Figure 2 illustrates the fruiting bodies of this fungus. With the aid of a magnifying glass one may often see them clearly as stiff black hairs, approximately 1 millimeter ($1/25$ th of an inch) in length,⁵ swollen at the bases, and forming, en masse, a dark hairy covering on the ends and tangential surfaces of stained sapwood. These growths when well developed are sometimes referred to by lumbermen as "whiskers."

Many species of *Ceratostomella* have been listed by Saccardo (40). Though no reference is made to the fact, it is probable that a number of these stain wood.

The life histories of many species of *Ceratostomella* found on stained wood have been worked out by Von Schrenk (41), Hedgcock (19), and Rumbold (37) in this country and by Münch (31) in Europe. In connection with the study of several chromogenic fungi which discolor wood, Hedgcock developed in culture a conidial stage of *Ceratostomella* superficially resembling *Cephalosporium*. Münch and Rumbold associated a *Graphium* stage with the development of

⁵ In some species the length may exceed 2 millimeters.

Ceratostomella. During the extensive culture work of Hedgcock, however, extending over a period of four or five years and involving

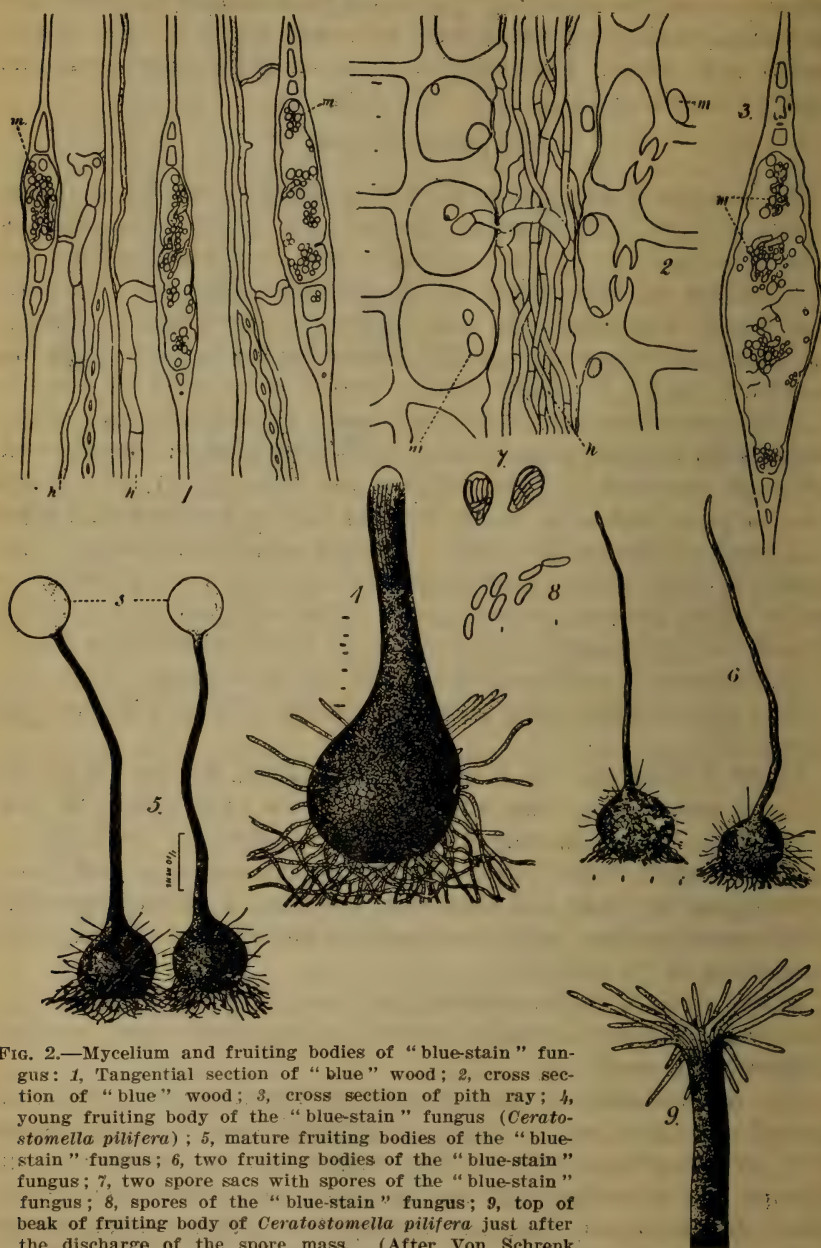
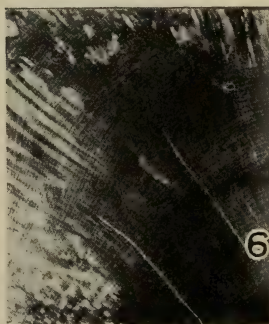
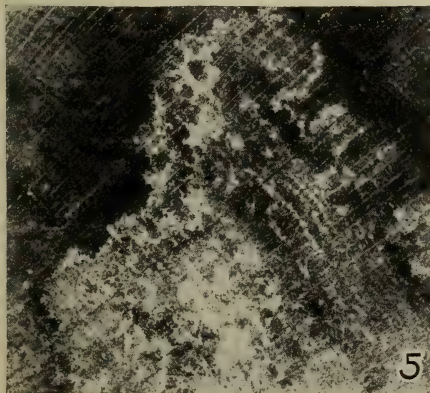
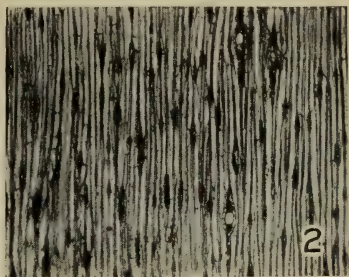
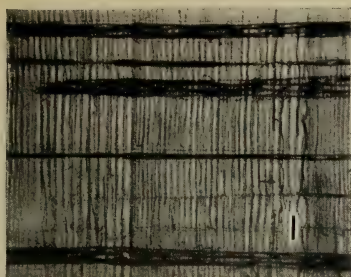


FIG. 2.—Mycelium and fruiting bodies of "blue-stain" fungus: 1, Tangential section of "blue" wood; 2, cross section of "blue" wood; 3, cross section of pith ray; 4, young fruiting body of the "blue-stain" fungus (*Ceratostomella pilifera*); 5, mature fruiting bodies of the "blue-stain" fungus; 6, two fruiting bodies of the "blue-stain" fungus; 7, two spore sacs with spores of the "blue-stain" fungus; 8, spores of the "blue-stain" fungus; 9, top of beak of fruiting body of *Ceratostomella pilifera* just after the discharge of the spore mass. (After Von Schrenk (32), pl. 7.)

a number of species of *Ceratostomella* from a variety of sources, no Graphium stage of this fungus was ever reported.



EXAMPLES OF WOOD INFECTION.—I.

FIG. 1.—Radial section of bull pine, showing hyphae of the blue-stain fungus growing in the pith rays. FIG. 2.—Tangential section of the same, showing many small hyphae growing into the adjoining cells. FIG. 3.—Log of southern yellow pine containing sap-stain. FIG. 4.—Mycelium of mold growing between hard-maple boards in a kiln. FIG. 5.—Mold on the end of a sawed red-oak billet. FIG. 6.—Maple billet containing sap-rot, a condition brought about through the agency of wood-destroying fungi. The surface has been polished to show more clearly the bleached and disorganized condition of the sapwood. (Figs. 1 and 2 are from Von Schrenk (41), pl. 8; fig. 4 is from a photograph by H. D. Tiemann.)



EXAMPLES OF WOOD INFECTION.—II.

FIG. 1.—Artificially infected blocks of red oak and white oak in the tile chamber ready for the steaming experiments performed at the Madison laboratory. The large white areas of mycelium on the ends of the blocks in the upper four rows are wood-destroying fungi and probably developed as a result of infection in the log. FIG. 2.—Sawed felloes of oak (species not known). Note the abundant growth of mold which had developed in the material during shipment and while in storage. Photographed by H. D. Tiemann.

Hedgcock (19) identified the following species of *Ceratostomella* as responsible for the discolorations produced in certain woods:

C. pilifera (Fr.) Wint., in the sapwood of several species of pine (*Pinus*), fir (*Abies*), oak (*Quercus*), and ash (*Fraxinus*).

C. schrenkiana n. sp., in short-leaf pine (*Pinus echinata* Mill.).

C. echinella E. and E., in freshly cut heartwood and sapwood of beech (*Fagus atropunicea* (Marsh) Sudworth).

C. capillifera n. sp., in wood of red gum (*Liquidambar styraciflua* L.).

C. pluriannulata n. sp., in blue sapwood of red oak (*Quercus rubra* L.).

C. minor n. sp., in Arizona pine (*Pinus arizonica* Eng.).

C. exigua n. sp., in dead and dying trees of scrub pine (*Pinus virginiana* Mill.).

C. moniliformis n. sp., in red gum (*Liquidambar styraciflua* L.).

Münch (31) split up *Ceratostomella pilifera* Fries into a series of new species, as follows:

1 *Ceratostomella pini*, the important blue-stain fungus of pine.

2. The pilifera group, distinguished by the secondary fruiting bodies:

(a) *C. piceae*, with an associated Graphium stage, possibly *Graphium penicillioides* Corda, in species of pine and fir.

(b) *C. cana*, with an associated but unclassified Graphium stage. This species he also found in pine wood.

(c) *C. coerulea*, having no associated Graphium stage.

With these species of *Ceratostomella* Münch includes two unrelated fungi, *Endoconidiophora coerulescens* and *Cladosporium* sp., as causing discolorations in coniferous timber.⁶

Von Schrenk (41), in his studies of the "blue wood" in dead and dying stands of the western yellow pine (*Pinus ponderosa* Laws.), found that the spores of *Ceratostomella* blown about by wind or carried by insects are often deposited in the exposed ends left by the breaking of branches or in the holes made by the bark and wood boring beetles. There, under the favorable conditions which usually prevail, they germinate and readily produce in a short time many colorless, branching hyphæ. The hyphæ grow into the bark tissues, then into the cambium, and from there into the medullary rays. With age the hyphæ take on a brown hue.

According to Von Schrenk (41, pp. 18, 19), "one of the first effects seen after the hyphæ have entered the medullary ray cells is the gradual solution of the walls separating the medullary ray cells from one another (fig. 2, 1, 2, 3). The walls which separate the ray cells from the neighboring wood cells may become very thin, as shown in the middle ray (fig. 2, 1), but they are rarely dissolved entirely. The intermediate walls, on the other hand, entirely disappear. This

⁶ In a recent publication, C. J. Humphrey (23) describes a fungus, *Lasiothraeria pezizula* (B. and C.) Sacc., as the cause of a blue-black stain in certain hardwoods, particularly beech and red gum. More detailed information concerning this fungus, as well as certain species of *Ceratostomella*, is given by E. E. Hubert (21).

leaves a tube, with a cross section having the shape of the cross section of the ray, extending into the trunk from the bark. This tube is sometimes filled entirely with a mass of brown hyphæ, the larger number of which extend in the direction of the ray (Pl. I, figs. 1 and 2). From the ray cells some hyphæ make their way into adjacent wood cells (fig. 2, 2; Pl. I, figs. 1 and 2).⁷ They grow along these, both up and down (fig. 2, 1), giving off branches to other wood cells. In this manner the whole wood body becomes penetrated by the brown hyphæ in a very short time after the first infection. The number of hyphæ in the wood cells proper, excluding the medullary ray cells and the cells of the wood parenchyma, is very small indeed. This is probably due to the fact that the fungus finds scant material upon which to live in the wood cells. The hyphæ are apparently able to puncture the unligified walls here and there, but they stop at that point. The writer was not able to demonstrate that the hyphæ could attack the lignified walls. In other words, the 'blue' fungus is one which confines its attack to the food substances contained in the storing cells of the trunk and to the slightly lignified walls of these storing cells." According to the same authority (41, p. 19), the resin ducts may be attacked in like manner (fig. 2, 3; Pl. I, fig. 2).

In the case of sawed timber it is quite probable that the fungous spores falling upon the surface of the sapwood find there the moisture and food material necessary for germination. Subsequently they give rise to a mass of mycelium, many of whose hyphæ enter the wood through the exposed medullary or pith rays and then probably invade the surrounding tissue, as explained by Von Schrenk.

SUSCEPTIBILITY OF VARIOUS WOODS TO SAP-STAIN FUNGI

The sapwoods of many kinds of timber are susceptible to sap-stain, though the degree of susceptibility varies considerably. Among the conifers southern yellow pine, western yellow pine, sugar pine, and the spruces seem to be readily stained and in the case of the broad-leaved trees, red gum, red oak, white oak, and hackberry seem to be particularly susceptible.

Often there is a considerable difference between a species when grown on the dry uplands and the same species when grown under the moist conditions characteristic of the lowlands (Von Schrenk and Spaulding, 44). This difference in woods of the same species may be even more marked when grown in essentially different climates (Spaulding, 48). It seems to be the opinion of many lumbermen that timber grown in the South is more susceptible to fungous attacks than timber grown in the North. If differences in susceptibility do

⁷ E. E. Hubert (21) observed in the wood of scrub pine and northern white cedar hyphæ of *Ceratostomella* sp., which had penetrated tracheids and wood fibers for a distance of several cells from the medullary rays.

exist in such woods it is difficult to state whether they are due to dissimilarities in mechanical structure, to the relative proportions of contained air and water, or to the variety and amounts of stored food present in the wood parenchyma and medullary rays. It is probable that differences in environmental conditions, i. e., temperature and humidity as affecting the growth of the fungi, are important factors directly responsible (Roth, 35, p. 55-56).

STRENGTH OF "BLUED" WOOD.

Since the wood fibers are not appreciably impaired by the growth of the blue-stain fungus, there should be no apparent loss in the strength of the invaded wood. Rudeloff (36) found that the compression strength of pine is not affected by the presence of bluing fungi. Tests on the stained wood of western yellow pine conducted at Washington University, St. Louis, Mo. (Von Schrenk, 41) and later at the Forest Products Laboratory, Madison, Wis. (Weiss, 56; Weiss and Barnum, 57) proved that there is practically no diminution in the end compression or cross-breaking strength and hardness of the stained as compared with the unstained wood. In the case of heavily stained shortleaf pine, however, tested at the latter institution, there was found to be a slight decrease in the strength, toughness, and hardness as compared with unstained wood having the same moisture content. It may be safely stated that blued wood is practically as strong as unstained wood.

CAUSE OF THE COLOR IN "BLUED" WOOD.

The cause of the blue color in the wood has never been satisfactorily explained. R. Hartig (17, p. 66) ascertained that it arises from the presence of the brown fungous hyphæ in the intercellular spaces. According to Von Schrenk (41, p. 18, 25-26), it appears in the wood when the colorless mycelium begins to take on the brown hue characteristic of the mature fungus. Microscopic examination of the wood fibers taken from the blued wood reveals no indication of a blue color. While extracts of the blue wood with alcohol, ether, benzol, chloroform, alkalis, and acids differ in appearance from those obtained from clear wood, yet no blue tinge is apparent. Von Schrenk (41, p. 26) suggests that possibly "there is some pigment with a blue element in the 'blue' wood which is so faint that its detection in thin microscopic sections becomes almost impossible." Hedgcock (19, p. 110-111) states that "the brown color of the fungus apparently contains traces of a blue pigment whose color is transmitted by the wood cells of the pine more readily than the brown color." Münch (31, p. 3) concludes that the color is due to the arrangement of the mycelial threads in the wood. He cites, as some-

what similar examples, the blue color of thin milk, cigarette smoke, and the clear sky, wherein very fine particles are held in suspension in a transparent medium.

OTHER FUNGOUS ORGANISMS CAUSING SURFACE DISCOLORATIONS IN GREEN TIMBER.

In addition to the blue-stain fungi, there is another group, the molds, which commonly occur upon the freshly cut surfaces of green timber when stored under moist, warm, and stagnant conditions (Pl. I, fig. 5; Pl. II, figs. 1 and 2). Molds are occasionally found growing vigorously upon timber in kilns (Pl. I, fig. 4). This is especially noticeable when the atmosphere of the kiln is exceedingly moist or saturated and the temperature ranges from 90° to 110° F.⁸ or from 110° to 130° F. (Tiemann, 51, p. 186-187).

Hedgcock (19) showed that the blackening and browning so common in the green sapwood of pine (*Pinus* sp.), poplar (*Populus* sp.), tulip (*Liriodendron* sp.), red gum (*Liquidambar* sp.), oak (*Quercus* sp.), maple (*Acer* sp.), and several other woods can often be traced to species of *Graphium*. He cites:

G. ambrosiigerum n. sp., on Arizona pine (*Pinus arizonica* Eng.).

G. eumorphum Sacc., on wild red raspberry (*Rubus strigosus*) and related species.

G. atrovirens n. sp., on red gum (*Liquidambar styraciflua* L.).

G. smaragdinum (A. and S.) Sacc., on red gum (*Liquidambar styraciflua* L.).

G. rigidum (Pers.) Sacc., on red oak (*Quercus rubra* L.).

G. aureum n. sp., on white pine (*Pinus strobus* L.).

G. album (Corda) Sacc., on beech (*Fagus atropunicea* (Marsh) Sudworth).

Graphium spp. are perhaps best known by the upright, cylindrical, occasionally branched fruiting bodies 1 to 3 millimeters in height (fig. 3). These are often brown to black in color and bear at the tips comparatively large and, in many cases, confluent globules composed of masses of spores embedded in a mucuslike substance. These spore masses, though usually cream color, vary somewhat in hue, and in some species are tinged with gray, brown, green, yellow, or red. While these are the organs of fructification commonly observed, other types less conspicuous and bearing the so-called secondary conidia have been demonstrated in culture by Hedgcock (19).



FIG. 3.—Fruiting body of *Graphium* sp. (After Münch, 31.)

⁸ Information from the section of timber physics, Forest Products Laboratory, Madison, Wis.

Other fungi mentioned by Hedgcock (19) as blackening wood are: *Alternaria tenuis* Nees., *Stachybotrys alternans* Bon., *Aspergillus niger*, *Chaetomium* sp., *Stemonitis* sp., *Gliocladium* sp., *Hormodendron* sp., *Hormiscium* sp., and *Cladosporium* sp. The apparent discoloration in these cases is due either to the presence of colored hyphæ in or upon the surface of the wood or to a luxuriant superficial growth of colored spore masses. In no case is it due to the secretion of any pigment which is absorbed by the wood.

Hedgcock (19) names three other species—*Penicillium aureum* Corda, *Penicillium roseum*, and a *Fusarium* sp. formerly included under *Fusarium roseum*—which, due to the secretion of soluble pigments, actually stain the wood red, purple, or yellow, according to the alkalinity or acidity of the medium. These stains are superficial, however, and readily dress off when the lumber is planed. Many other molds grow readily upon green sapwood and give the timber a displeasing appearance, though they cause no deterioration in the strength of the wood. From the material collected by the writer and sent to the Madison laboratory there have been isolated over 40 distinct species of fungi. With the exception of species of *Ceratostomella* and *Graphium*, together with a species of *Fusarium* which was identified by Dr. Mabel M. Brown, graduate student at the University of Wisconsin, as *F. arthrosporioides*, this number consists of fungi popularly known as molds. The determination of the molds was made by Dr. Charles Thom and Miss Margaret B. Church, of the Bureau of Chemistry, United States Department of Agriculture. They are listed below:

<i>Aspergillus flavus</i> series.	<i>Penicillium asperulum</i> or <i>puberulum</i> .
<i>Aspergillus niger</i> .	<i>Penicillium brevicaulis</i> series.
<i>Aspergillus repens</i> .	<i>Penicillium commune</i> .
<i>Aspergillus versicolor</i> group.	<i>Penicillium divaricatum</i> .
<i>Cephalothecium roseum</i> .	<i>Penicillium lilacinum</i> .
<i>Citromyces</i> sp.	<i>Penicillium luteum</i> .
<i>Cladosporium</i> sp.	<i>Penicillium purpurogenum</i> .
<i>Clonostachys</i> sp.	<i>Penicillium roqueforti</i> .
<i>Gliocladium</i> sp.	<i>Penicillium rugulosum</i> .
<i>Haplographium</i> sp.	<i>Penicillium solitum</i> .
<i>Monilia sitophila</i> .	<i>Syncephalastrum</i> sp.
<i>Mucor</i> sp.	<i>Trichoderma</i> sp.
<i>Oidium</i> sp.	

The great variety of genera and species here noted contains many earth dwellers and indicates that the molds commonly found upon green timber, especially during storage and transit, are for the most part soil forms whose spores have by accident fallen upon the moist surfaces of the sapwood and there found the conditions favorable for development.

It has generally been supposed that the growth of mold on wood is confined mainly to the surface or, at the most, to the superficial

layers, perhaps a few cells in thickness. H. Marshall Ward (55), however, in connection with certain experiments upon spruce blocks which had been artificially infected with *Penicillium* sp., notes that the examination of sections from cultures 3 months old showed that the hyphæ of this fungus had entered the starch-bearing cells in the medullary rays of the sapwood and had consumed the starch. The hyphæ were observed deep in the wood extending from tracheid to tracheid through the bordered pits. Miss A. L. Smith (46) notes the presence of a dark-brown hyphomycete in decaying timber. This mycelium had invaded the woody tissue and had apparently brought about a partial destruction of the medullary rays (see also Freeman, 12).⁹

During a series of experiments by the writer, cultures were taken from various points within red-oak blocks $2\frac{1}{2}$ by $2\frac{1}{2}$ by 10 inches long which had been cut from green sapwood and then artificially infected with 15 different fungi including 13 of the common molds.¹⁰

The results obtained seem to confirm Ward's experiments, for positive mold cultures were secured even from the center of these blocks. However, as far as known, the molds do not cause any serious disintegration of the cell walls in green timber and thus do not impair the strength of the wood to any appreciable extent. As in the case of the blue-stain fungus, it is the stored food within the cells that is the object of attack.

The principal objection to the presence of mold lies in the discoloration due to the masses of mycelium and the luxuriant clusters of fruiting bodies which often develop upon green sapwood, and sometimes the heartwood, under conditions of high humidity and temperature resulting from poor ventilation. However, these superficial growths are readily removed during sanding or planing operations. In many cases they can be readily brushed off. This is particularly true of material which has become surface dried.

An inspection of a carload of moldy timber is quite likely to produce an impression that is liable to react unfavorably upon the shipper. Moreover, the presence of much mold or sap-stain in timber indicates the existence of conditions which are favorable to the development of decay. Such material, then, should be viewed with suspicion, but not of necessity with unfavorable discrimination.

FACTORS WHICH FAVOR THE GROWTH OF SAP-STAIN AND MOLD FUNGI.

The development of fungi is dependent upon four factors—a supply of air, containing the essential element oxygen; the requisite

⁹ McBeth and Scales (30) list a considerable number of molds that are apparently able to destroy cellulose, though they act differently toward different kinds of cellulose.

¹⁰ See page 29 for the list of fungi used in this experiment.

amount of moisture; a temperature range within certain limits; and the necessary food substances.

Air.—Fungi require oxygen for their growth. This is supplied as one of the constituents of ordinary air. Even under storage conditions the supply is ample. Stagnant air containing a considerable amount of moisture is favorable to the growth of fungi in the timber, in that it prevents the drying of the wood. Timber entirely submerged in water is practically immune from fungous attacks, since the supply of oxygen is cut off.

Moisture.—The extent of the growth of sap-stain and mold fungi is largely dependent upon the amount of moisture present in the substratum. This moisture content in green timbers of different species as well as in the sapwood and heartwood of a particular species may vary considerably. Thus, according to Tiemann (51, p. 106; 33, tables), the green sapwood of conifers may contain from 100 to 150 per cent moisture,¹¹ while the heartwood, probably being near its fiber saturation point, contains about 30 per cent. In the case of the hardwoods, both heartwood and sapwood may contain from 60 to over 200 per cent moisture. Frequently, however, there is present a greater quantity of free water in the sapwood than in the heartwood (Tiemann, 51). In air-dried timber the amount of moisture may be reduced to anywhere from 8 to 18 per cent, according to the climate. In kiln-dried material it may be reduced to 3 to 15 per cent moisture, depending upon requirement and uses. This will explain why mold and sap-stain, so frequently found in green timber, are absent in thoroughly air-seasoned or kiln-dried stock. Air currents will often surface-dry the timber to an extent that will make it practically impossible for fungi to grow thereon.

The relative quantities of water and air found in the wood, according to Von Schrenk (43), are the most important factors in the control of the rate of growth and spread of the sap-stain fungus. He cites Münch's experiments (32) on artificially inoculated pine blocks,¹² differing only in the relative amounts of contained water and air. These experiments seem to indicate that the growth of the fungus is inhibited when the normal winter water content of the wood is raised to an amount that will insure a consequent reduction in the volume of contained air to at least 15 per cent, based on the volume of the fresh wood. According to Münch (32) an air content of 42 per cent, brought about through a reduction of the normal winter water content of the wood, is the optimum for development of the fungus in the wood. Münch (31, p. 59-62) states that the sap-stain fungus at-

¹¹ Unless otherwise stated, all percentages of moisture content are based upon oven-dry weight.

¹² The blocks in this case were artificially inoculated with the conidia of *Ceratostomella coerulescens*.

tacks recently felled trees, but does not penetrate deeply, owing to the high water content of the wood. He also states that the mycelium of the fungus readily penetrates throughout the sapwood of winter-felled wood when the loss in water content amounts to 10 to 20 per cent. Moreover, the growth in moist wood takes place for the most part in the older layers of the sapwood, or those in proximity to the heartwood. Finally, Münch concludes that the sap-stain fungus is capable of infecting the living tree, thus becoming parasitic, provided the fungous spores find entrance to the sapwood through injuries to the bark, such as those produced by bark-boring beetles; and that conditions favorable for fungous growth, namely, a reduction in the water content and a corresponding increase in the air content of the sapwood, are brought about through disturbances in the root system of the tree.

In this connection certain investigations by Snell (47) on the relation of the amount of decay to the density of the wood should be mentioned. Five fungi which had been found to cause the rotting of structural timber in New England cotton mills were grown upon blocks of loblolly-pine sapwood and Sitka spruce. Several series of these blocks, each series containing a different percentage of moisture, were used in these experiments. The results obtained with loblolly pine agreed in the main with those of Münch (32) upon Scotch pine, a wood of about the same density. In the case of Sitka spruce, a wood of considerably less density, however, it was found that the limits of moisture content favorable for fungous growth were raised. In other words, "the values representing the upper limits for decay will vary inversely with the density of the wood."

Temperature.—It has been clearly demonstrated in a number of temperature tests¹³ upon some of the molds derived from infected timber that these fungi grow readily between certain limiting temperatures. Beyond these, they cease to show any signs of activity. The optimum temperatures are commonly those which obtain during the late spring and summer months in certain parts of the country, particularly in the South, i. e., 80° to 85° F. It is probable, however, that each species has its own characteristic range.

Food.—Sap-staining fungi and molds have been shown in cultures to live upon quite a variety of foods. Being devoid of chlorophyll they can not, like the higher plants, manufacture their own food, but must depend upon that already available. The medullary rays and wood parenchyma of green sapwood often contain certain starches, sugars, and oils which represent the stored food of the tree. These are the substances upon which sap-staining fungi probably depend for their existence.

¹³ These tests were conducted at the Forest Products Laboratory, Madison, by Mrs. Rose Harsch Lynwalter.

When supplied with the essentials necessary for growth, fungi develop rapidly and often reproduce abundantly. Deprived of any or all of these factors, however, the vegetative portion, i. e., mycelium, ceases to grow and eventually dies. In some cases, as, for instance, certain molds, the spores may retain their vitality for long periods under extremely unfavorable circumstances. When favorable conditions return, these spores soon germinate and often develop an abundant growth of mycelium within a few days. Fruiting bodies, sometimes bearing countless spores, may then make their appearance, and the life cycle is repeated. The ideal conditions for growth are often to be found in green timber containing a high percentage of sapwood when exposed to the stagnant atmosphere of the woods, poorly ventilated sheds, warehouses, and cars during warm, sultry, or rainy weather. Under such circumstances the sapwood may become thoroughly infected within a few days. Sap-stain may thus appear soon after infection with spores or mycelium of the sap-stain fungi. Wood-rotting fungi may also get a good hold upon timber under such conditions, and symptoms of incipient decay later become apparent (Pl. I, fig. 6).

DURABILITY OF STAINED OR MOLDED WOOD.

Since the blue stain and mold fungi cause little or no dissolution of the wood fibers, they do not affect directly the durability of the timber. If properly piled and dried, stained or moldy wood stock free from decay should not deteriorate further from the action of the fungi. However, the conditions which favor the development of sap-stain, mold, and sap-rot are much the same, namely, the presence of spores or mycelium of the particular fungi capable of producing these defects in wood, a substratum containing the requisite food material, moisture, and a high relative humidity (75 to 100 per cent), a temperature of 70° to 100° F., and a lack of circulation of the air, or stagnation, which retards or prevents the proper drying of the timber. There seems to exist among many lumbermen a false notion that mold and sap-stain represent early stages in the development of sap-rot, or "dote," as it is commonly called. While the presence of an abundant growth of mold or sap-stain in green stock indicates conditions which are likely to favor the growth of rot, it is well known that the rot is caused by a distinct group of true wood-destroying fungi which develop independently.

Molds in general develop rapidly. Hence, they may be often found growing profusely on green timber already infected with rot-producing fungi long before the latter have exhibited any noticeable evidence of their presence. It is possible, however, for wood destroyers to infect and bring about the disintegration of wood which contains no trace of mold or any other organisms.

LOSSES DUE TO SAP-STAIN OR MOLD.

INSANITARY PRACTICES IN THE HANDLING OF GREEN WOOD STOCK.

As a result of investigations in the woods, inspections of many carloads of green timber and dimension stock upon arrival at the mill, examinations of green and seasoned manufactured stock upon arrival at the vehicle factory, and talks with practical millmen and lumbermen, the writer is convinced that a considerable amount of the damage to vehicle stock, due to fungi, is brought about through the use of infected raw material. Many of the infections take place in the woods, as a result of insanitary practices in the handling of logs, bolts, and split billets. In many instances, during warm and humid weather logs and bolts have been allowed to lie in the woods for weeks. Under such conditions sap-stain is almost certain to follow. Moreover, the liability to attack by wood-destroying fungi is greatly increased.

Split billets, instead of being cross piled on dry foundations, are sometimes thrown carelessly about the stump and left until a convenient time for hauling arrives. Under favorable circumstances it takes but a few days for certain fungi to gain a good hold on such stock, and unless later checked or destroyed by some process such as kiln drying, they may produce a permanent stain or decay in the sapwood.

It is quite probable that a serious shortage of cars suitable for handling the logs, bolts, and billets may prevent at times the rapid movement of raw stock to the mills. This results in the accumulation of material in the woods and railroad yards and contributes to conditions in many cases favorable to the development of the fungi. Frequently box cars are used where in normal times the more open and consequently better ventilated types of car would be employed.

Failure to observe proper measures during storage, such as the use of dry foundations for logs and bolts, the cross piling or stripping of billets on dry foundations sufficiently high to give suitable ventilation from beneath, and the storage of stock in properly ventilated sheds, has furnished conditions suitable for the development of mold, sap-stain, and decay in such material.

A few millmen seem to have the mistaken idea that an abundant growth of mold on green stock serves to protect it from checking by preventing evaporation from the surface of the wood and actually absorbing, or possibly condensing, moisture from the surrounding atmosphere and then transmitting it to the wood. The fungus derives its moisture from the wood, not the air. Its presence, however, often indicates a high humidity in the immediate vicinity, a condition which prevents the drying of the wood and thus favors the growth of fungi. It is quite probable that the phenomenon known as gutta-

tion, i. e., the collection of minute drops of excreted water upon the fungous growth, is responsible for the misconception.

In some instances split billets upon being unloaded from the cars are thrown in a pile beside the track, sometimes upon damp soil, there to remain for perhaps a month or until opportunity can be found for removal to storage sheds. Losses due to fungi are a natural consequence of such treatment.

It has taken time for those unaccustomed to the handling of green stock to work out satisfactory methods which would provide proper ventilation of dimension, sawed, or turned stock during transit. Meantime, many shipments have been seriously damaged. Of the different forms of stock, the sawed billet, the rim strip, and plank have given the most trouble. Losses are not confined to such stock, however, for turned spokes and hubs, unless properly safeguarded during transit, are liable to stain and mold.

Sawed billets often arrive at the factory in a badly stained condition. It is probable that material containing fungous infections sometimes finds its way into their manufacture. The squared surfaces lend themselves to close piling and thus to the formation of masses wherein sufficient ventilation is impossible. Rim strips also frequently become badly stained while in transit, as a result of the same causes, together with the fact that some manufacturers require such stock to be close piled in closed box cars and even sprayed with water to prevent checking. It is unfortunate that the conditions necessary for the prevention of checking in green stock are as a general rule favorable to the growth of fungi, and vice versa.

ECONOMIC IMPORTANCE.

The presence of much sap-stain and even mold in timber is considered by some lumbermen as a defect. Therefore, degrading of material thus affected, with consequent loss in monetary value, may result. Such unfavorable discrimination is due to the notion that stained or moldy material is not as sound as clear stock. In the case of molds, it is an easy matter to remove the surface blemish by the simple process of sanding or planing. With sap-stain, however, the removal of the discoloration depends entirely upon the depth to which the mycelium has penetrated. In some cases the stain may extend to the heartwood. It is evident that it can not under such circumstances be removed by the processes referred to.

The presence of much stain will prevent the use of timber for purposes where color, texture, and clearness of grain are of prime importance. Basket and box veneer, interior finish, flooring, and furniture stock which are to have no protecting coat of paint must be free from stain. Discrimination, however, should not be made

against sap-stained or moldy stock that is to be covered, provided there is no incipient decay associated with it.

The reduction in the value of stained lumber sometimes amounts to \$2 or more per 1,000 feet, board measure, and perhaps one-fourth of the annual mill cut of the United States is attacked. In one year it was estimated that the total losses from sap-stain amounted to between 8 and 9 million dollars (Weiss, 56; Weiss and Barnum, 57; see also Pratt, 34). The amount in any locality, however, depends upon the climate, the season, and several other factors.

Weather conditions have a marked influence upon the amount of damage to freshly cut timber in the woods or to green stock in storage and in transit. During warm and moist weather such stock will sometimes stain badly and in a short time, unless it is properly safeguarded. This, of course, is due to the fact that the warm and humid conditions stimulate the development of the fungi. It follows, then, that the greater losses from sap-stain, sap-rot, or mold should be expected during the warmer months, and especially during those months in which both high temperatures and high humidity normally prevail. As a matter of fact, this is the case. In the months of April, May, June, July, and sometimes August and even September, depending upon climatic conditions, the greatest damage occurs. In the South, owing to the prevailing high temperatures and relative humidities, the losses are often extremely severe. The greatest losses occur in low-grade coniferous lumber, especially the southern pines, owing partly to the high percentage of sapwood and partly to the fact that the low-grade lumber is seldom kiln dried, but is stacked in the yard to air season. Under such circumstances, unless unusual precautions are observed, it is very liable to the attacks of the sap-stain fungi.

From replies to the questionnaires sent out by the wood-stock committee to contractors and producers of wood stock regarding sap-stain and mold in vehicle stock and from the data derived from the personal investigations of the writer, it was learned that these losses are dependent largely upon the manner in which the stock is piled in the cars and sheds during transit or storage. The losses average less than 10 per cent, but may reach from 25 to 75 per cent. The writer was informed that because of such damage to green spokes during the summer of 1918, sometimes as many as 50 per cent in a carload lot were culled. When turned spokes were selling at \$150 per 1,000 feet b. m., the loss on a carload containing perhaps 12,000 escort spokes, $2\frac{1}{2}$ by $2\frac{1}{2}$ by 27 inches, was evidently considerable, perhaps amounting to hundreds of dollars. One firm reported that it had knowledge of entire carloads being destroyed. In some instances cars had gone astray and had finally reached their proper destina-

tion after one or two months on the road. Losses in those cases were often practically complete. Sixteen different firms reported that for the year 1917 their individual losses due to "heating in transit," as staining is sometimes explained by lumbermen, varied from \$100 to \$5,000. One company reported the losses as varying from \$25,000 to over \$75,000 in different years.¹⁴

CONTROL MEASURES.

A great many attempts have been made to devise measures for the control of sap-stain and mold in green timber. With the exception of kiln drying, however, none of these has proved entirely satisfactory. When tried under circumstances unfavorable to the growth of fungi, some of these measures have met with considerable success, but when put to the test under conditions which stimulate fungous development, they have often failed. For the most part they have been prophylactic rather than curative in nature. However, it is believed that many of the following measures, although not entirely effective, will assist materially in reducing losses due to sap-stain, mold, and incipient decay in green stock.

HANDLING IN THE WOODS.

AUTUMN AND WINTER CUTTING.

Many lumbermen (15) think that, where possible, timber should be cut in the autumn and winter. While this is probably true, the reason often given is incorrect. The statement is usually made that winter cutting is better because the "sap is down." It has been shown by T. Hartig (33, tables; Janka, 26) that during the spring when the growth is most active the treesometimes contains less water than in the winter. It is probable that the changes in moisture content which do take place are confined mainly to the sapwood. It is true that the movement of sap is much more rapid at the time of active growth and that there are important chemical changes which take place therein during the different seasons of the year. In the winter, insoluble starches and gums are stored in the sapwood. During the spring these are changed to soluble sugars and are borne through the living tissues. The sapwood of summer-cut logs, therefore, contains soluble foods which render it extremely susceptible to attacks by fungi during the warm months when these organisms are most active. Winter-cut logs, on the other hand, have an opportunity to season under conditions less favorable for fungous growth and by the time warm weather

¹⁴ National Implement and Vehicle Association and other Vehicle and Vehicle Parts Manufacturers. Information Division of the Wagon and Vehicle Committee and the Wheel Manufacturers' War Service Committee. Wood Stock Committee. Sap-stain and mold in transit. Nat. Implement and Vehicle Assoc., etc., Bul. 30, 5 p. 1918. A. B. Thielems, chairman. Typewritten.

arrives will have dried to a degree which will render them less susceptible to fungi (Roth, 35, p. 57).

In the bottom lands of the South, however, autumn and winter cutting may not always be feasible owing to the wet and muddy conditions then prevailing, which make hauling difficult, if not impossible.

Incidentally, leaf seasoning (Tiemann, 51), i. e., girdling trees while in full leaf and then allowing them to remain, often for years or until the leaves have entirely shriveled up, with the idea that much of the free water in the sapwood will be drawn off by transpiration through the leaf surfaces and thus prevent sap-stain, does not seem to be practiced in the regions visited by the writer. Although this method is said to be common in the seasoning of teak in India and has been advocated by some as applicable to gum in this country, yet it does not seem to meet with general approval, because it exposes the timber to the ravages of insects and to fungi causing decay.

RAPID HAULING.

One of the precautionary measures to be observed, especially during the late spring and summer, is that of hauling timber immediately after felling. Raw stock can not be gotten out of the woods and to the saw too rapidly. It is possible for fungous infections to take place at all times of the year on the exposed surfaces of freshly cut timber. These develop more rapidly, however, during warm, humid weather, and especially under the conditions which obtain in the woods.

STORAGE IN THE WOODS.

If it is found necessary to allow logs and bolts to remain in the woods, they should be so separated that the ends are left several inches apart. If the sawed ends remain in contact, fungi are liable to develop between them. Some have recommended that logs that are to remain in the woods during the summer be painted on the exposed ends with creosote (Von Schrenk, 42). It has been considered advantageous by some (Von Schrenk, 42; see also Hartig, 18) to remove the bark from logs that must of necessity be left in the woods for an extended period. Advocates of such treatment state that the peeled surfaces soon become air-dried and consequently provide insufficient moisture for the germination of any fungous spores that may fall thereon. In order to keep such logs off the damp ground and thus assist in the air-drying process measures must be taken to provide some sort of temporary foundation free from stain, mold, or rot.

When it becomes necessary to store split billets in the woods, they should be piled with only two billets in a course and should rest upon

a foundation located on dry ground and consisting, where possible, of billets of split heartwood free from rot.

HANDLING RAW STOCK IN TRANSIT.

TYPES OF CARS.

In shipping green stock to be used in the manufacture of vehicles, etc., the following types of cars have been preferred:

Flat cars	logs (fig. 4).
Gondolas or stock cars	bolts (fig. 5).
Stock or vegetable cars	split billets or dimension stock.
Ventilated box cars	lumber or dimension stock.



FIG. 4.—Unloading logs from a flat car. This is the type of car usually used for the shipment of logs.

PROVISIONS FOR THE PROPER VENTILATION OF STOCK IN TRANSIT.

Well-ventilated types of cars should be selected where possible, if staining and molding are to be prevented (figs. 4 to 10). Preparatory to use, these cars should be thoroughly swept free from rubbish, damp sawdust, lime, or manure. In the case of box cars, it is important that the roofs be carefully inspected to make sure that they are water-tight. If it becomes necessary to use box cars for the transportation of split billets during the late spring and summer months, it is suggested that the billets be ricked and that strips or occasional crossers of the same stock at intervals of 12 to 16 inches be used to assist in the ventilation of the pile. Side doors should be open and both doorways boarded up, leaving at least 11½-inch spaces between the boards. If box cars are equipped with small

end doors of the ventilating type, these doors should be left open and the doorways cleated to prevent the stock from working out during transit. Lumber shipped in box cars must be stripped.

HANDLING RAW STOCK IN THE YARDS.

STORAGE OF LOGS AND BOLTS.

When piling or cording logs and bolts in the yard for storage, it is important that they be kept off the ground by the use of clean skids or permanent foundations of seasoned fungus-free planks, stone, or cement. Such foundations should be placed on well-drained soil free from underbrush or weeds that might interfere with proper ventilation from beneath.



FIG. 5.—Bolts loaded in a gondola car. Gondolas, stock, or vegetable cars are best adapted to the transportation of this type of raw stock.

STORAGE OF BILLETS.

BILLETS that are not turned at once should be stored upon dry foundations and in properly ventilated sheds (fig. 11). When sufficient storage space is available, the method of piling used by one of the large wheel manufacturers in the North, shown in figure 12, is recommended.

STORAGE OF GREEN LUMBER.

The methods of piling lumber are pretty well understood and need little explanation here (?).¹⁵ In general, it is well to select a location

¹⁵ For information concerning this point, the reader is referred to Bulletin No. 552, United States Department of Agriculture (7), copies of which may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents per copy.

on well-drained soil free from weeds and one which will allow the prevailing winds to blow through the sides rather than upon the ends of the stacks.

Care should be taken to provide suitable foundations consisting of metal or well-seasoned heart stock, preferably creosoted and resting upon piers of creosoted wood or, better, of stone, brick, concrete, or metal. All foundations should be sufficiently high to allow for ventilation vertically through the stacks. Moreover, there should be ample space between the stacks to permit a free circulation of the air around them. Finally, it is important that narrow strips, perhaps 1 inch wide and at least 1 inch thick, of well-seasoned, kiln-dried, or chemically treated wood be used between all courses and that they be carefully placed in vertical alignment to prevent warping of the stock.¹⁶

HANDLING AT THE MILL.

EARLY MANUFACTURE.

Logs, bolts, and split billets should be sawed into dimension stock or planks and manufactured as soon as possible. This will do much toward safeguarding the material by reducing the time in storage.

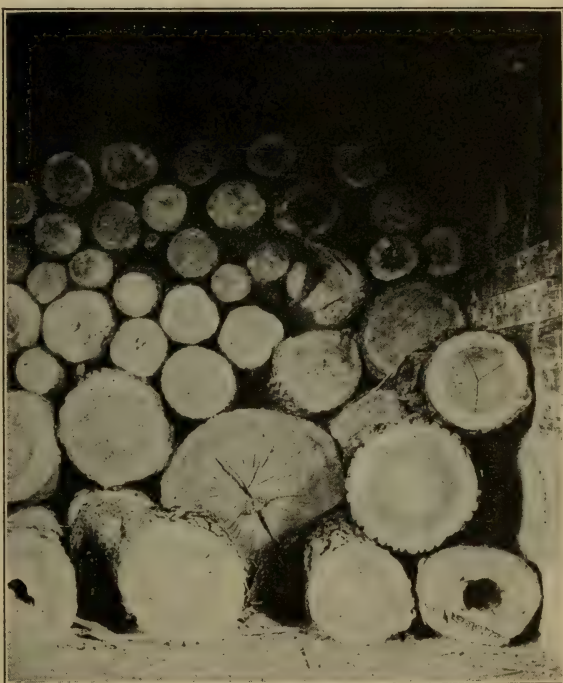


FIG. 6.—Bolts piled in a box car. Note the débris on the floor of the car. Bolts are likely to suffer from fungous attacks when shipped in box cars with the doors closed.

AIR SEASONING.

Provided kilns are not available, the dimension stock should be seasoned from six months to a year or more, depending upon the

¹⁶ The general sanitation of lumber yards and the proper methods to be observed in the piling of timber to prevent or reduce losses in storage due to fungi, together with a consideration of the more common rot-producing organisms, are clearly described by Humphrey (22), in Bulletin No. 510, United States Department of Agriculture. Copies may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 20 cents per copy.

size and kind of material.¹⁷ When sufficiently dry, shipments in closed box cars will suffer little or no loss from sap-stain or mold. In all cases where air seasoning is resorted to, unless great care is exercised in providing for ample circulation of air through the stock by such means as open piling, fungous and insect troubles are likely to develop. It is absolutely necessary to strip or cross pile the stock upon dry foundations. For purposes of stripping, kiln-dried or chemically treated strips 1 inch wide and at least 1 inch thick should

be used between courses. All sheds for the storage of this material should be dry and well ventilated.

KILN DRYING.

By far the most effective and quickest method of treating green stock, as a prophylactic measure, to destroy fungi or insects and to reduce shipping weight, is to subject the material to proper kiln drying. When producers are equipped with, or have access to, modern kilns op-



FIG. 7.—Split billets piled in a box car. When occasional billets are used as crossers and the doors of the car are cleated open this type of spoke stock suffers but little while in transit.

erated on a scientific basis and are so situated that stock can be moved rapidly, less concern need be given to fungous troubles. Kiln-dried spokes can be bundled or close piled in dry warehouses or in ordinary box cars and shipped without loss.

Material kiln dried directly from the saw has been shown to be just as good as air-seasoned stock (Tiemann, 51, p. 300) and in many cases much better as far as strength, toughness, and freedom from defects are concerned. Moreover, the time necessary for seasoning can often be reduced from one year to three weeks or from three to five years to as many months.

¹⁷ The reader is again referred to Department Bulletin No. 552 (7) for information concerning the seasoning of wood.

Kiln drying reduces shipping weight; makes the lumber fit for almost immediate use; eliminates or reduces losses due to insects,¹⁸ or to checking, rotting, staining, or molding; improves the quality of the lumber; reduces the amount of yard space; and saves the tying up of capital and carrying costs (Tiemann, 51, p. 4, 5).

It is possible that where several producers are located within a few miles of one another, a battery of modern dry kilns, operated according to the most approved methods (possibly on the community plan) might solve the problem of cost of installation and operation.

In dry kilns, stripping or cross piling the stock and providing means to prevent stagnation of the confined air are absolutely necessary if the development of mold is to be avoided. The water spray kiln devised at the Forests Products Laboratory represents one of the latest developments in the temperature and humidity-controlled type of kiln.¹⁹

During the first few weeks of kiln drying, when the humidity is high and the temperature ranges from 80° to 105° F., an abundant

growth of white mycelium occasionally forms between the courses and interferes more or less with the circulation of the air in the kiln. This is due to the presence of mold fungi, and it usually indicates stagnation in the kiln (Pl. I, fig. 4). Steaming for one hour at a temperature of 160° to 180° F. has been found effective in destroying or at least checking the growth of this mold (Tiemann (51), p. 187).



FIG. 8.—Split billets loosely piled in the areaway between the doors of a box car. The doorways are loosely boarded up to allow for ventilation of the car and at the same time prevent the stock from working out while in transit.

¹⁸ Powder-post beetles, however, are said to cause considerable damage at times in seasoned stock; in fact, these beetles do not work in green stock.

¹⁹ A complete description of this kiln is given in Bulletin No. 509, United States Department of Agriculture (52), a copy of which may be procured from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 5 cents. Further information concerning the design and installation of this kiln is given in Bulletin No. 894, United States Department of Agriculture (50), to be procured from the same source at 10 cents a copy.

STEAMING GREEN STOCK AS A CONTROL MEASURE.

METHODS COMMERCIALY EMPLOYED.

Steaming certain kinds of stock (green gum lumber, birch hubs, spokes, and sawed felloes of red or white oak) is sometimes resorted to as a means of reducing shipping weight by hastening drying or to even up the color and reveal defects in the wood.

In the steaming of green gum lumber a large steel tank, or preparator, is employed. The lumber loaded upon trucks is run into this preparator and steamed for perhaps 15 to 30 minutes at pressures of 20 to 30 pounds (figs. 13 and 14). Provided this lumber is

then carefully open piled, it remains clean. When close piled or when exposed to adverse weather conditions, however, it may mold almost as readily as untreated green lumber.

Hubs, sawed felloes, and turned spokes green from the saw are sometimes steamed at atmospheric pressure. At one plant visited, green birch hubs were stacked in large cement boxes and subjected to exhaust steam for 24 to 36 hours, depending upon the size of the



FIG. 9.—A box car loaded with split billets upon its arrival at the spoke mill. The method of loosely boarding the doorway, as shown in figure 8, is preferable in that there is less danger of the stock working out while in transit. When, however, the masses of billets are held in position by supports, or when vertical boards are nailed a few inches back of the cleats, this method may be used. Both provide for the ventilation of the stock.

hub. At the end of that time the steam was shut off and the hubs were allowed to cool for perhaps 10 hours. The hubs were then carried to a ventilated warehouse and stacked, zigzag fashion, to provide for ample circulation of the air through the inside as well as around them. In this manner an even drying was secured. Two to three weeks was considered a sufficient length of time for the necessary air drying previous to shipping. During the warmer months, stock cars were used as means of transportation.

The steaming of gum and birch is a comparatively simple process. But in the case of woods that check readily, such as oak, this treatment requires considerable care.

THE EXPERIMENTAL STEAMING OF RED-OAK AND WHITE-OAK BLOCKS AT THE LABORATORY OF FOREST PATHOLOGY, MADISON, WIS.

During the spring of 1919 the writer performed several series of experiments at the Madison laboratory to determine the efficiency of steam at atmospheric pressure in destroying mold and sap-stain fungi in artificially infected red or white oak blocks $2\frac{1}{2}$ by $2\frac{1}{2}$ by 10 inches. Incidentally the rate of drying and the amount of checking were noted in connection with the steaming.

The blocks were sawed from the sapwood of summer-cut logs, weighed, and then sprayed with a water suspension of spores taken from cultures of mold fungi originally derived from infected material sent in by the writer. A list of the fungi used in these experiments follows:

Aspergillus flavus.
Aspergillus niger.
Cephalothecium roseum.
Ceratostomella sp.
Citromyces sp.
Graphium sp.
Monilia sitophila.
Mucor sp.
Penicillium asperulum.
Penicillium divaricatum.
Penicillium luteum.
Penicillium pinophilum.
Penicillium rugulosum.
Synecephalastrum sp.
Trichoderma sp.



FIG. 10.—Square billets close piled in a box car. This type of raw stock suffers considerably when piled in the manner shown here. Stripping or cross piling while in transit or storage is essential if losses from fungi are to be avoided.

The sprayed blocks were then placed in a tile chamber, which served as an incubator. After several weeks in this chamber, where an average relative humidity of 95 per cent and an average temperature of 70° F. prevailed, the blocks became well infected and developed countless numbers of the fruiting bodies peculiar to the fungi mentioned above (Pl. II, fig. 1).

A steam box was constructed of cypress, equipped with thermometers, dew-point apparatus, and manometer and connected with the main which supplies steam to the laboratory greenhouse (figs. 15 and 16). By means of suitable reducing valves in the connecting pipes it was possible to control the steam pressure in the box; hence, the



FIG. 11.—Stacking sawed billets in an open shed. It will be observed that the billets at the extreme right are cross piled, while those in the center are close piled. The former method of piling insures a better ventilation of the stack, provided intervals of at least 1 inch are left between the adjacent billets of a course. In the case of the cross-piled billets shown here this provision was not made.

exact conditions to which the blocks were subjected could be readily determined. Steam at atmospheric pressure only was used.

Previous to steaming, the blocks were again weighed. They were then close piled or stripped in groups of 25 in the steam box and steamed for different lengths of time. At the end of the steaming period, some of the lots were allowed to cool for a certain time and then reweighed. Others were weighed immediately. Nearly all were put in a small ventilated box in the open and allowed to air-dry for several weeks. Some, however, were placed in a closed shed for four weeks, and still others were taken

from the steam box, weighed, and placed directly in the tile chamber. Some lots were stripped; others were close piled. An interval of at least 3 inches was maintained between adjacent piles.

After the preliminary seasoning mentioned above, a number of the blocks were returned to the tile chamber for incubation. This was done for the purpose of subjecting the blocks to the conditions existing in box cars and poorly ventilated warehouses during warm and

sultry weather. The tile chamber, when given a preliminary treatment, which consisted of intermittent steaming for three successive days to reduce the amount of viable fungous growth therein, provided these conditions admirably. In this chamber the temperature was maintained at an average of 85° F., while the relative humidity varied from 70 to 95 per cent. At the end of four weeks in the tile chamber the blocks were removed and their condition with respect to molding noted.

The following observations were made from several series of experiments:

The amount of drying which took place in the steam box was comparatively slight. This seemed to depend, however, upon the relative moisture content of the wood previous to steaming. Green blocks usually lost, while partly seasoned blocks often gained in weight.

Beyond a certain length of time, dependent upon the moisture content of the wood and the surface area of the blocks in relation to volume, there seemed to be little gained, in so far as the reduction in weight was concerned, by continued steaming. Six or nine hours' steaming seemed to be no more efficient than three hours in the case of the 2½ by 2½ by 10 inch blocks.



FIG. 12.—Diagram illustrating one method of stacking green split billets. This method is used by one of the large wheel factories of the North. When ample storage space in well-ventilated sheds is available, this method is recommended.

Steamed blocks subsequently dried more rapidly than those that were simply air-dried.

Open piling or stripping in the steam box was preferable, in that it permitted a better circulation of the steam in the box and thus insured a more uniform treatment of the blocks.

The amount of checking varied in the several lots when steamed under the same conditions. This may have been due to the fact that the blocks differed considerably in the relative proportion of sapwood and heartwood present.

The greatest amount of checking occurred in those lots that were subjected to rapid cooling and surface drying by exposure to air currents from open doors and ventilators. Blocks allowed to cool in the steam box with doors closed seemed to suffer least in this regard. Slow cooling was, in some cases, brought about by opening a small hatch in the roof of the steam box at the conclusion of the steaming period.

The total amount of checking which had taken place in the steamed blocks, both during the steaming process and the subsequent period of air seasoning, extending over four months, exceeded but little that noted in those blocks which had been simply air seasoned for the same length of time.

Steaming seemed to be effective in killing the fungi in the infected blocks when employed for a period of three hours. Cultures taken from various points

in or upon the blocks by means of a sterile scalpel and needle gave no growth, while cultures taken from check blocks which had not been steamed gave positive results in every case.

Steamed material, unless open piled under conditions which insured an ample supply of circulating air, molded almost as readily as green stock.

Steamed blocks that were given a month's air drying subsequent to steaming and previous to storage under the extreme conditions that prevailed in the tile chamber showed a little more resistance to the invasion of fungi than those blocks that were placed in the tile chamber immediately after steaming.

It is quite probable that the steam treatment of wood stock, followed immediately by prolonged submersion of the material in some of the antiseptic solutions to be described later, might prove to be a



FIG. 13.—Boards of red gum loaded on a truck and ready to be rolled into the preparator (shown in fig. 14).

fairly effective method for the control of fungi in infected stock. This treatment might be applied to special classes of wood stock where the margin of profit would justify the extra cost.

THE CHEMICAL TREATMENT OF GREEN WOOD STOCK.

Many attempts have been made to find some chemical compound or mixture that, when applied as a dip, will control sap-stain and mold in green timber. A great many substances have been tried, but none have proved entirely satisfactory. Under conditions not particularly favorable to the growth of fungi, several have met with considerable success. On the other hand, if the conditions were stimulating to fungous growth, the same substances often failed. Some treatments depend for their efficiency upon the neutralization of the acids in the wood and, at the same time, the establishment of

alkaline conditions. To this group belong sodium carbonate, sodium bicarbonate, sodium hydroxid, lime, and borax. Others are intended to poison the food of the fungi, and comprise such compounds and mixtures as mercuric chlorid, copper sulphate, sodium fluorid, creosote, and many other substances.

Toxicity tests (Humphrey and Fleming, 24)²⁰ conducted at the Madison laboratory upon a few molds commonly occurring upon infected timber, as well as upon several wood-destroying fungi, have clearly demonstrated that when the entire culture medium is permeated with these and many other preservatives, often in very small amounts, the growth of the fungus can be readily inhibited. Hence,



FIG. 14.—Preparator used for the commercial steaming of red-gum lumber at one of the mills in Arkansas.

if wood be thoroughly impregnated with a solution of one of these common preservatives it will be protected from decay as well as from sap-stain and mold.

This is quite possible in the case of thoroughly seasoned timber impregnated with preservatives by subjection to high pressure in closed retorts. The penetration of green timber by cold solutions of salts in an open tank or by the brush treatment, however, is extremely slight.²¹ Tests made by the writer for the presence of copper in the interior of $\frac{3}{4}$ by $\frac{3}{4}$ by $1\frac{1}{2}$ inch blocks sawed from the green

²⁰ Information also obtained from unpublished reports of toxicity experiments performed by Miss C. Audrey Richards at the Laboratory of Forest Pathology, Madison, Wis.

²¹ For a description of the pressure, open-tank, and brush treatments, the reader is referred to Forest Service Bulletin No. 78 (45) and to Farmers' Bulletin 744 (25), U. S. Department of Agriculture.

sapwood of red oak and then dipped for 10 seconds in solutions of copper nitrate and copper sulphate at ordinary temperature showed that these solutions had penetrated the ends of the blocks for a distance less than 5 millimeters (one-fifth of an inch) and scarcely a measurable amount in the case of the tangential or radial surfaces. It is evident, then, that whatever value there is in the use of cold dipping solutions lies entirely in the superficial coating of the preservative left upon the wood. Provided this is not brushed off or washed off by rain, it may inhibit or prevent the germination of fungous spores which happen to fall upon such surfaces. Hot solu-

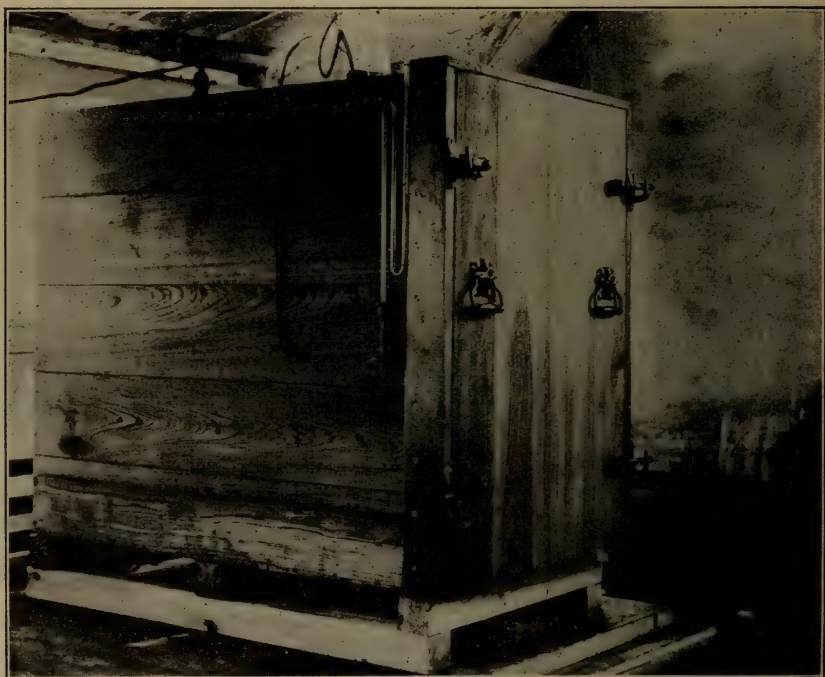


FIG. 15.—Steam box of cypress used in the experimental steaming of red-oak and white-oak blocks at the Madison laboratory.

tions, in that they tend to prevent the collection of bubbles of air upon the surface of the wood, probably give a more uniform distribution of the preservative over the dipped material. As far as penetration is concerned, however, it is doubtful whether the hot solutions, as ordinarily employed, possess any very great advantages. A slightly increased penetration may be secured by first subjecting the stock to a thorough steaming or by heating it for some time in a hot solution of the preservatives, as in the open-tank process. The air within the cavities of the wood is thereby expanded, and some escapes. Provided the steamed or hot wood is at once transferred to a cold solution of the preservative and there allowed to remain till

cool, an amount, approximately equal to the original volume of the escaped air, will be forced into the wood. This is a slow process, however, and therefore somewhat expensive.

The rate of evaporation of the liquid, in the case of hot solutions, is much greater than in cold solutions; hence, it becomes necessary to take frequent hydrometer readings of the bath and to make the proper adjustments in the relative proportions of the solvent and dissolved substances in order to maintain a uniform concentration.

Dipping may be of some value when applied to stock free from fungi. In those cases where the fungi are already in the timber, however, it is doubtful whether very much good can result from chemical dips unless the material be subjected first to a relatively high temperature and for a length of time sufficient to destroy these organisms.

The salts used in the chemical treatment of lumber are likely to vary considerably in strength and purity. It is probable that the lack of uniformity in the results obtained by different investigators when employing nominally the same compounds may be traced partly to this cause. A few of the preservatives commonly used are described here.

SODIUM CARBONATE AND SODIUM BICARBONATE.

The substances which have been most frequently employed to prevent sap-stain in lumber are sodium carbonate (commonly in the form of soda ash) and sodium bicarbonate (baking soda). Solutions of these salts are applied either hot or cold by dipping in an open tank. On southern yellow pine, when used in concentrations of 4 to 5 per cent sodium carbonate and 5 to 6 per cent sodium bicarbonate, these

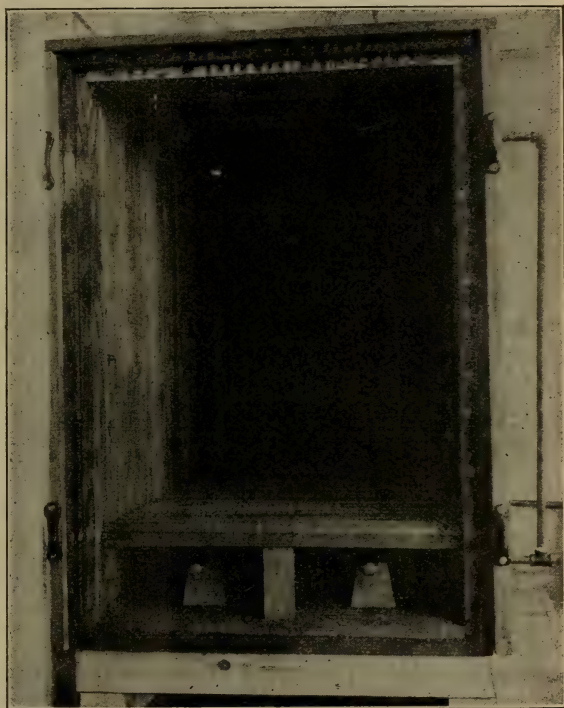


FIG. 16.—Details of the interior of the steam box used in the experimental steaming of red-oak and white-oak blocks at the Madison laboratory.

substances have given more or less satisfactory results (Weiss and Barnum, 57). In wet weather, however, it has been found necessary practically to double the strength of the solutions. Moreover, both sodium carbonate and sodium bicarbonate cause a yellow to brown discoloration of the wood. Lumber treated with these preservatives must be open piled or it may mold and stain badly during warm, humid weather.

A good grade of sodium carbonate in the form of soda ash should contain 58½ per cent alkali, while the amount present in sodium bicarbonate (baking soda) is about 37 per cent. Solutions of the latter are more or less decomposed at temperatures above 158° F., giving off carbon dioxid. In a series of laboratory experiments followed by practical field tests on southern yellow pine and red gum, Rumbold (37) found that the blue-stain fungus is sensitive to alkalis but not to acids, that an 8 per cent solution of sodium carbonate is as effective as an 11 per cent solution of sodium bicarbonate, and that the amount necessary to prevent growth varies with the substratum. Freshly cut sapwood of southern yellow pine or red gum required 8 per cent sodium carbonate and 10 per cent sodium bicarbonate solutions under conditions which were especially favorable for the growth of the blue-stain fungus. In dry weather a weak solution of the alkali (a 5 per cent solution of sodium carbonate and a 4 per cent solution of the bicarbonate) kept the yellow pine boards free from stain. It was also observed that the spores of the blue-stain fungus are more resistant than the mycelium. These experiments seem to show that sodium carbonate and sodium bicarbonate possess some value as a preventive against sap-stain but that the success attending the treatment is largely dependent upon weather conditions.

SODIUM FLUORID, SODIUM BIFLUORID, AMMONIUM FLUORID.

Sodium fluorid, which has proved to be very toxic to wood-destroying fungi (Teesdale, 49), has also been tested to determine its toxic properties in connection with the blue-stain fungus. Representatives²² of the Forest Products Laboratory, working independently and in cooperation with certain lumber mills located in Mississippi and Louisiana, found that both sodium fluorid and sodium bifluorid were effective against sap-stain. The fluorids have an advantage over sodium carbonate and sodium bicarbonate in that they do not discolor the timber. One of these investigators, in a comparative series of experiments with a number of preservatives, including 2½ per cent sodium fluorid, 2½ per cent sodium bifluorid, and 2½ per cent ammonium fluorid, found that in the concentrations mentioned these salts were fairly effective against sap-stain. The ammonium fluorid,

²² Unpublished reports by Pettigrew and Knowlton in the files of the Forest Products Laboratory, Madison, Wis.

in addition, seemed to be of some value in controlling mold. However, both of these series of experiments were performed during hot and dry weather—conditions unfavorable to fungous growth; hence, it is impossible to draw satisfactory conclusions from the results.

While the fluorids may be effective in controlling decay and, to a certain extent, stain-producing organisms, they can not be depended upon to prevent molding.

MERCURIC CHLORID.

Probably the best antiseptic to prevent sap-stain and mold in green wood stock is mercuric chlorid. When used on coniferous woods and on many of the hardwoods in concentrations of 0.1 per cent to 1 per cent, it has been found to be exceedingly efficient. The addition of 0.1 to 1 per cent hydrochloric acid is said to increase its stability. Mercuric chlorid, however, is extremely poisonous when taken internally. Many individuals show a marked susceptibility to the poison even when applied externally. Moreover, the solutions of mercuric chlorid are corrosive to iron, zinc, and many other metals commonly employed in dipping vats. For these reasons it can not be recommended for general use.

SOME RESULTS OBTAINED FROM THE USE OF ANTISEPTICS BY VARIOUS INVESTIGATORS.

It is probable that the efficiency of a given antiseptic varies considerably when applied to woods of different species and at various stages of air seasoning. As stated before, the results are likewise dependent upon climatic conditions. On open-piled boards of shortleaf pine in Missouri, Von Schrenk, Bessey, and Spaulding found that 5 per cent sodium bicarbonate or one-twentieth per cent mercuric chlorid gave good results (Hedgcock, 20). On open-piled white pine in Wisconsin, the first two investigators found that the solutions giving the best results were 5 per cent borax and 2.5 per cent sodium bicarbonate, while on boards of Norway pine in open piles 5 per cent borax, one-twentieth of 1 per cent mercuric chlorid, and 2.5 per cent sodium bicarbonate were most effective (Hedgcock, 20). As the result of experiments on longleaf pine boards in open piles at Bogalusa, La., Weiss and Barnum (56, 57) concluded that the most effective antiseptics for the control of sap-stain, in that wood at least, are mercuric chlorid in concentrations of 0.1 to 1 per cent and sodium bicarbonate in strengths varying from 5 to 10 per cent. In these experiments 5 per cent borax gave poor results.

Hedgcock (20), in connection with certain experiments at Baltimore, Md., on the prevention of mold and stain in veneer baskets made from poplar, sycamore, beech, gum, and maple, found that the most effective solutions were 10 per cent sodium carbonate, 6.5 and 10 per cent sodium bicarbonate, 2.5 per cent sodium bicarbonate plus

0.66 per cent borax and boric acid, 0.20 per cent sulphur plus 0.20 per cent lime, 0.10 per cent mercuric chlorid plus 0.20 per cent hydrochloric acid, 10 per cent potassium (alum), and 0.33 per cent phenol salicylate. He concludes that of these substances, 5 to 10 per cent sodium bicarbonate is the safest and best to use.

In nearly all the cases cited the antiseptics proved to be of some value in preventing the growths of the sap-stain fungus. Molds, however, are extremely resistant to chemical treatment and consequently are difficult to control. To quote from Lafar (28): "Whether the waterproof character of some cell membranes, e. g., the conidia of *Penicillium* and *Aspergillus*, should be attributed to



FIG. 17.—Barrels and steam-coil connections as used in the experimental dipping of red-oak spokes at one of the large spoke mills in the South.

the deposition of excreted fatty or waxy substances must be left undetermined. Biologically this phenomenon is important, since it prevents the penetration of toxic substances from the aqueous medium and thereby also opposes the attempts of the mycologist to kill such fungi by means of aqueous toxic solutions." Since, as has been stated repeatedly, molds develop largely on the surface of the timber and are sufficiently removed during the several finishing processes to which the timber is sooner or later subjected, their presence in most cases should occasion but little concern in connection with vehicle stock.

EXPERIMENTAL DIPPING OF RED-OAK SPOKES.

DIPPING.

In July, 1918, several series of experiments were performed by the writer in cooperation with one of the large spoke mills of the

South. It was desired to test in a more practical way some of the antiseptics that had been used on a small scale during preliminary experiments at the Madison laboratory. In these experiments first-grade escort spokes $2\frac{1}{2}$ by $2\frac{1}{2}$ by 27 inches long of red oak were used. They were selected mainly for two reasons: First, red oak in a green condition was the wood, of all those used at this particular mill, which seemed to be the most liable to mold and sap-stain; second, the escort spoke was convenient to handle in connection with the dipping apparatus employed.

All spokes were taken directly from the warehouse after turning and grading. It was noted that 80 to 90 per cent of them contained sapwood varying in amount from 5 to 100 per cent.

In lieu of dipping tanks it was decided to use whisky barrels of 50-gallon capacity. Three of these were placed on a platform in the mill yard beside the tracks upon which the trucks were operated. One barrel was equipped with a steam coil of bent $\frac{1}{2}$ -inch iron pipe provided with shut-off valves (fig. 17). This coil, when connected with the main steam boiler, supplied the necessary heat for maintaining the temperature of the dipping solutions. A piece of corrugated, galvanized-iron plate, approximately 2 by 6 feet, when supported in a slanting position with the lower end resting upon the top of the barrel, served as a drain board. Iron tongs similar to those used by blacksmiths, hydrometers, thermometers, and a gallon measure completed the list of essential apparatus.

The following antiseptics were applied in the form of solutions or in a dry state:

- (a) Barrett's grade 1 liquid creosote, 10 per cent by volume.
Perfection kerosene oil, 90 per cent by volume.
Temperature, 80° to 90° F.
- (b) Barrett's grade 1 liquid creosote, 10 per cent by volume.
Perfection kerosene oil, 90 per cent by volume.
Temperature, 150° to 155° F.
- (c) Powdered borax, 5 per cent by weight.
Water, 95 per cent by weight.
Temperature, 80° to 90° F.
- (d) Mercuric chlorid (C. P.), 1 per cent by weight.
Hydrochloric acid (commercial), 1 per cent by weight.
Water, 98 per cent by weight.
Temperature, 80° to 90° F.
- (e) Dry salt (finely grained).
- (f) Dry quicklime (finely powdered).

The spokes were conveyed to the dipping barrels on trucks. There they were grasped by means of the iron tongs, immersed from 5 to 10 seconds in the bath, and then placed on the corrugated-iron drain board (fig. 18). When practically all of the excess liquid had drained off they were again grasped with the tongs, loaded upon another truck, and wheeled to the north end of one of the open sheds

in the yard. There they were unloaded, close piled, and allowed to remain until ready for shipment.

During the dipping operation it was observed that in some cases as many as 10 to 15 per cent of the untreated spokes in a given truck load showed the presence of sap-stain. In one lot the number showing sap-stain and mold was estimated at 50 per cent. Other lots were practically free from fungi. During the experimental work the weather was for the most part hot and dry. Following one or two light showers the amount of mold on untreated material showed a marked gain.

The methods of dipping were similar for all baths except in the case of the hot creosote. Here, the steam coil was employed and a



FIG. 18.—The experimental dipping of red-oak spokes green from the lathe.

temperature of 150° to 155° F. maintained. One barrel served for both cold and hot creosote. The borax was dissolved by aid of the steam coil in the second barrel. A third barrel was necessary for the mercuric-chlorid dip. Thermometer and hydrometer readings were taken at frequent intervals, and whenever necessary corrections were made to maintain a constant temperature and concentration in the bath.

Incidentally, it was noticed that ambrosia beetles were very quickly killed by the creosote dip, a point of importance to consider in controlling insect pests which at times, especially during warm and damp weather, are said to cause considerable losses in piled lumber.²³ (Weiss, 56, p. 18-20.)

²³ A certain species of beetle, *Dendroctonus ponderosae* Hopk., has been mentioned by Von Schrenk (41) as being partly responsible for the dissemination of the spores of the blue-stain fungus.

Both cold and hot solutions of creosote may cause considerable irritation, and in some cases blistering, when brought in contact with the skin. By proper use of the tongs, however, this trouble was avoided. Rubber gloves were worn during the dipping of spokes in the solutions of mercuric chlorid, since that salt, as already stated, is a deadly poison when taken internally and is sometimes absorbed through the skin when solutions are handled continuously.

Many metals, such as iron and zinc, possess the common property of precipitating metallic mercury from the solutions of its salts. For this reason the iron tongs and other metallic objects could not be used in connection with the mercuric-chlorid dip.

The spokes that were treated with salt or lime were placed, a few at a time, in wooden boxes containing the respective substances in a finely powdered state and were rolled to distribute the chemicals over them as evenly as possible. The excess was shaken off. They were then close piled in one section of the warehouse. After 24 hours the lime coating showed a marked tendency to absorb moisture and cake. Moreover, it turned the wood dark. For this reason the liming was discontinued after 300 spokes had been treated. The salted spokes soon became exceedingly moist, due to the hygroscopic nature of the salt. The antiseptics used and the number of spokes treated in the different lots follow:

(a) 10 per cent creosote in kerosene, cold-----	5,100
(b) 10 per cent creosote in kerosene, hot-----	5,100
(c) 5 per cent borax in water-----	1,013
(d) 1 per cent mercuric chlorid plus 1 per cent hydro- chloric acid-----	1,000
(e) Dry salt-----	1,032
(f) Dry quicklime-----	300

The first lot went forward in a box car loaded to capacity with 5,000 cold-creosoted spokes, 5,000 that had been hot creosoted, 800 spokes that had been dipped in mercuric chlorid, and 350 that were untreated. It was originally intended to ship the other lots at the same time. The car, however, was found to be too small, so the borax-treated, salted, and limed spokes went forward at a later date.

Many of the cold-creosoted spokes that had lain in the shed for two to three weeks awaiting shipment were slightly molded. It was noticed that those with the mold were taken from that part of the pile that had suffered most from poor ventilation, namely, near the bottom and in the rear. The spokes in the other lots at that time seemed to be free from mold or sap-stain.

METHOD OF LOADING CAR NO. 1.

The spokes were stacked in transverse ricks, beginning at the end of the car and working toward the doorway. Each rick was built up in the following manner. A row consisting of five pairs of spokes

all parallel to the length of the car was laid across the floor. An interval of perhaps 1 or 2 inches separated the members of a pair, and the distance between successive pairs was made a little less than the length of a spoke. Upon either end of these was laid a single transverse row of spokes. A third layer similar to the first and a fourth similar to the second were then laid down. With two more alternate layers a comparatively open base six layers in height and providing for partial aeration of the ricks was constructed. Upon this base the remaining spokes of the rick were close piled in successive layers, two or three spokes in depth. Each alternate horizontal layer was placed at a slight angle to those directly above and below, but all had a general direction lengthwise of the car. Each rick when built to within 2 feet or so of the roof contained on an average 833 spokes. As soon as one end of the car had been filled ricks were placed in the opposite end. In the doorway three longitudinal ricks were constructed and any space remaining was filled in with loose spokes. In this particular case one end of the car was stacked with the hot-creosoted spokes, the opposite end and $1\frac{1}{2}$ ricks in the doorway being stacked with the cold-creosoted spokes. Parts of two ricks in or near the doorway comprised spokes treated with mercuric chlorid, and the remainder consisted of untreated spokes thrown in loosely between the longitudinal ricks and the doorway. Both doorways were boarded up with 6-inch boards spaced $1\frac{1}{2}$ inches apart, and both doors were left open for about 1 foot. This car left the yard on July 24, consigned to one of the large vehicle factories of the North and reached its destination on August 14. On August 15 and 16 it was unloaded and inspected by C. J. Humphrey and the writer. During the time that the car was in transit the weather was in general hot and dry, although local showers may have been encountered.

CONDITION OF SPOKES IN CAR NO. 1 UPON ARRIVAL AT DESTINATION.

The inspection at the time of arrival was very thorough, each spoke being handled separately and a record kept of the number showing mold in any degree. Observations were also made, in a general way, of the extent of sap-stain and incipient rot. No attempt was made to discriminate between heavy and light infections, as these largely depended, with a given preservative, on the position of the spokes in the ricks or in the car with respect to the amount of ventilation received. In general, the top layers to a depth of 15 to 18 inches showed very little mold; likewise, the loosely arranged bases were quite free or comparatively so. The molds consisted for the most part of fluffy white to tawny mycelium, together with a comparatively small amount of green *Penicillium*. In the case of the cold-creosoted spokes, there seemed to be an increase over the amount

which was observed on the same spokes at the time of loading. For convenience in presentation, the data relative to location in the car and condition are given in Table I.

TABLE I.—*Condition of the red-oak spokes in car No. 1 upon arrival at its destination.*

Location in car. ^a	Antiseptic.	Condition.	Percent- age molded (based on 833 spokes per rick).
Forward end of the car:			
Loose in the doorway.	Untreated.....	Free from mold or sap-stain; a few badly checked.	.....
Stacked in the doorway and first rick.	Mercuric chlorid and hydrochloric acid.	None with mold or sap-stain; not so many checked as in the untreated lot.	.....
First rick.....	Hot creosote at 150° to 155° F.	None with mold; no sap-stain.....	.....
Second rick.....	do.....	68 with mold; no sap-stain.....	8.2
Third rick.....	do.....	431 with mold; no sap-stain.....	51.7
Fourth rick.....	do.....	277 with mold; no sap-stain.....	33.2
Fifth rick.....	do.....	218 with mold; no sap-stain.....	26.2
Sixth rick (end of the car).	do.....	222 with mold; no sap-stain.....	26.7
Opposite end of the car:			
Stacked in the doorway and first rick.	Cold creosote at 80° to 90° F.	69 with mold; no sap-stain.....	8.3
Second rick.....	do.....	492 with mold; no sap-stain.....	59.1
Third rick.....	do.....	348 with mold; no sap-stain.....	41.8
Fourth rick.....	do.....	207 with mold; no sap-stain.....	24.8
Fifth rick (end of the car).	do.....	142 with mold; no sap-stain.....	17.0

^a Ricks are in each case numbered from the first transverse rick on either side of the area between the doors and extending back to the ends of the car.

It will be seen from Table I that the spokes that were placed in the doorway where better ventilation could be had did not mold or sap-stain. Those that were the most exposed, however, were inclined to suffer from checking. The largest proportion of molding took place in the second or third ricks, but in no case was this accompanied by sap-stain, and in no instance was it severe enough to necessitate culling. The considerable reduction in the fourth and fifth ricks, which was most marked in the rear end of the car, is difficult to explain. In the forward end, the motion of the train caused the last rick to slide away from the end of the car, and thus somewhat improved the ventilation. It is possible, then, that in the rear end the tendency of the mass of spokes to surge backward and forward whenever the continuous passage of the car was interrupted, together with the fact that a hole existed in the bottom of the car due to the breaking of a floor plank, may have provided sufficient ventilation to account for the low percentage of mold in the fourth and fifth ricks.

It was noted that the stage in the development of the mold on the creosoted material was an early one, namely, a white, fluffy mycelium, which in most cases had not advanced to the spore-producing condition. This indicates a retarding effect due to the treatment. It is

also evident that the creosote, though unable entirely to control the mold, seemed to prevent the development of sap-stain. From the evidence it would also appear that heating the creosote to 150° or 155° F. does not increase its effectiveness to any marked degree, the difference in the percentage of moldy spokes in the two treatments being less than 1 per cent.

METHOD OF LOADING CAR NO. 2.

The second car, containing 1,032 salted, 1,013 borax-treated, 300 lime-treated red-oak, and the remainder untreated, white-oak escort

spokes, was loaded on August 3 and 5.

Those spokes that had been salted were exceedingly moist, owing to the hygroscopic property of the salt. On many of these species of *Penicillium* were found. The limed spokes were dark in color and in a few cases seemed to be developing sap-stain. The borax-treated spokes were apparently quite free from fungi.

The method used for stacking the spokes in the second car differed somewhat



FIG. 19.—“Ricking,” or stacking, treated escort spokes in a box car (car No. 2).

from that in the first. The base of each rick was constructed in the same manner, though of four instead of six layers. Upon this base the spokes were carefully stacked, using two 1½-inch by ¼-inch crossers of elm between successive layers (fig. 19). Each rick held on an average 840 spokes. The doorways were closed in the same manner as in car No. 1. This consignment left the yard on August 6 and arrived at the same factory located in the North on August 20, a period of two weeks in transit. During this time the weather was hot and comparatively dry.

CONDITION OF SPOKES IN CAR NO. 2 UPON ARRIVAL AT DESTINATION.

On August 21 the spokes were unloaded and inspected by C. J. Humphrey and the writer. Table II gives the location of the different lots and their condition upon arrival.

TABLE II.—Condition of the spokes in car No. 2 upon arrival at its destination.

Location in car.	Material.	Antiseptic.	Condition.	Percentage molded (based on 840 spokes per rick).
Ricks in the end of the car containing treated spokes:				
First rick	White oak	Untreated	147 moldy; a few sap-stained	17.5
	do.	A few untreated layers at top	1 moldy	.1
Second rick	Red oak	Remaining layers borax, 5 per cent.	67 moldy; many sap-stained.	7.9
	do.	Top layers borax, 5 per cent.	7 moldy; many sap-stained	.8
Third rick	do.	Middle layers lime	4 moldy; some sap-stained.	.4
	do.	Spokes very dark in color		
	do.	Bottom layer salt	34 moldy; some sap-stained	4.0
Fourth rick	do.	Salt	300 moldy; many with Penicillium in all parts of rick, badly damaged.	35.7
Fifth rick	White oak	Untreated	330 moldy; much sap-stain	39.3
Sixth rick	do.	do.	292 moldy; much sap-stain	34.8
Ricks in the doorway and in the opposite end of the car:				
In doorway	do.	do.	No mold; no sap-stain	0
First rick	do.	do.	87 moldy; many sap-stained	10.4
Second rick	do.	do.	312 moldy; many sap-stained	37.1
Third to sixth ricks.	do.	do.	Not examined	

The proportion of infected spokes, based on the total number in the different lots in the end of the car containing these spokes, is:

Untreated	29 per cent moldy.
Salted	32.3 per cent moldy.
Borax (treated)	7.3 per cent moldy.
Lime (treated)	1.3 per cent moldy.

These figures can by no means be used as a basis for an exact comparison of the values of the three preservatives. The location of the ricks in the car introduces another and very important factor. To note whether the hygroscopic property of the salt had a tendency to affect the humidity in the end of the car in which the salted spokes were stacked, thus influencing, perhaps, the amount of molding in adjacent lots, it was decided to observe the unloading of the spokes in the opposite end of the car. After two ricks had been unloaded, however, it became evident that this was not the case, as conditions in that end were practically the same as in the first. From the data derived, at least from this lot, given in Table II, it would seem that salt when applied dry to green spokes is of little value in controlling either sap-stain or mold. Lime, though effective in preventing both mold and sap-stain, yet because of its darkening effect on the wood and its tendency to form calcium carbonate, which cases over the surface and is said to dull the knives used in subsequent processes of manufacture, is debarred from further consideration. Borax, however, with 7.3 per cent moldy spokes, seems to be somewhat effective against mold, but of less value in controlling sap-stain.

SUMMARY OF OBSERVATIONS.

Creosote dipping seemed to prevent sap-staining, but it had little effect upon mold. In no way did it detract from the sale value of the spokes.

The creosote bath at 80° to 90° F. was nearly as effective as at 150° to 155° F.

Mercuric chlorid, 1 per cent, seemed to be very effective in controlling both sap-stain and mold.

Borax solution, 5 per cent, appeared to be somewhat effective in controlling mold, but of less value in regard to sap-stain.

The use of lime in the treatment of spokes was not satisfactory, on account of its darkening effect on the wood, the covering up of physical defects, and the probability of dulling the knives used in later processes of manufacture.

Salt sprinkled over the spokes was of no value in preventing either mold or sap-stain.

The ventilation of spokes in a box car is an important factor.



FIG. 20.—Green turned spokes cross piled in open or ventilated sheds. Green spokes are sometimes allowed to surface dry in this manner for one to two months preparatory to shipping in box cars.

Those spokes in the doorway, even if untreated, usually have but little tendency to mold or sap-stain.

Practically none of the spokes in either car were culled on account of defects due to fungi, although a few in the areaway between the doors were thrown out on account of slight checking.

No incipient decay was found in any of the material.

EXPERIMENTAL DIPPING OF RED-OAK BLOCKS AT THE LABORATORY OF FOREST PATHOLOGY, MADISON, WIS.

A comparison of the specific antiseptic values of the chemical substances employed in the spoke-dipping experiments can hardly be made, since these substances were not used in solutions of uniform strength. To determine, if possible, the comparative values of these and several other common antiseptics and preservatives in the control of mold and sap-stain fungi, several series of experiments were undertaken at the Madison laboratory. Where possible, solutions were made up to a calculated value of 1 per cent actual weight of anhydrous salt. The hygroscopic substances—sodium chlorid, calcium chlorid, and glycerin—were added in certain instances to determine whether or not they would increase the efficiency of the preservative by keeping the surface of the treated wood moist. A list of the substances used follows:



FIG. 21.—Storage of spokes in a warehouse. The truck spokes at the left have just been painted by girls with a resin-linseed oil mixture to prevent checking.

Alum (potassium).	Potassium chlorate.
Ammonium fluorid.	Sodium fluorid.
Bleaching powder.	Sodium bifluorid.
Borax.	Zinc silicofluorid.
Copper sulphate.	Creosote in kerosene.
Lead acetate.	Formalin.
Lead nitrate.	Lysol.
Magnesium silicofluorid.	Mykantin.
Mercuric chlorid.	Orthonitrophenol.
Mercuric chlorid and hydrochloric acid, 1 per cent.	Rongalite.

Red-oak blocks $\frac{3}{4}$ by $\frac{3}{4}$ by $1\frac{1}{2}$ inches long, sawed from the sapwood of summer-cut logs, were used in each case. Ten blocks constituted a group. The individual blocks of a group were immersed for approximately 10 seconds in one of the respective solutions, drained, and then sprayed on all six sides with a water suspension of the spores taken from the same cultures as those used in the steaming experiments.²⁴ The sprayed blocks of each group were then close piled and placed in the tile chamber mentioned on page 29. An in-

²⁴ See page 29 for the list of fungi.

terval of at least $1\frac{1}{2}$ inches was maintained between adjacent groups. In the tile chamber the blocks were subjected to a temperature averaging 80° F. and a relative humidity varying from 85 to 100 per cent. At the end of three to four weeks all blocks were carefully examined. The following observations were made at that time:

None of the preservatives was entirely effective in controlling mold when used in concentrations of 1 per cent.

Blocks dipped in sodium carbonate, sodium bicarbonate, sodium fluorid, sodium bifuorid, ammonium fluorid, magnesium silicofluorid, zinc silicofluorid, and bleaching powder became badly molded.

Potassium (alum), potassium chlorate, and copper sulphate seemed to stimulate all or certain species of the fungi used. The last seemed to incite the growth of *Aspergillus niger* in particular.

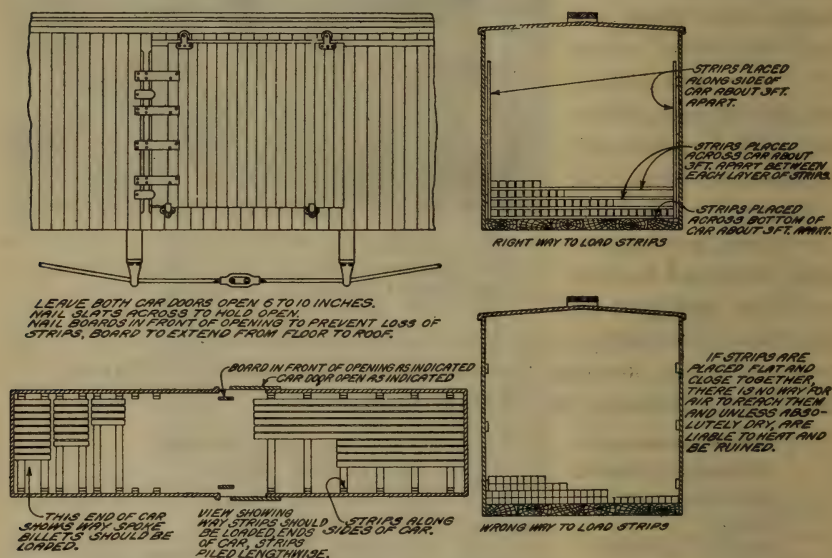


FIG. 22.—Diagram illustrating the method of loading used by one of the large wheel factories and recommended by the wood-stock committee in connection with vehicle stock.

Borax was effective in controlling the sap-stain fungus (*Ceratomyces* sp.). Though it did not entirely prevent the growth of mold, the amount of mold that did develop was very slight in comparison with that on the blocks treated with the other preservative solutions. Under these circumstances it compared favorably with 1 per cent mercuric chlorid.

The addition of the hygroscopic substances—sodium chlorid, calcium chlorid, and glycerin—to the solutions of the preservatives apparently did not increase their efficiency.

Of the organic compounds and mixtures tested here, creosote in kerosene gave the best results, while mykantin stood second. The latter, however, stained the wood yellow, a property which would prohibit its use for many purposes.

STORAGE OF GREEN DIMENSION, SAWED, OR TURNED STOCK AT THE MILL.

If it becomes necessary to store dimension or turned green stock without giving it the protection referred to, cross piling or stripping in properly ventilated sheds is absolutely essential (figs. 20 and 21). All strips should be narrow and at least three-fourths of an inch, but preferably 1 inch, in thickness and should be thoroughly seasoned or given some antiseptic treatment.

HANDLING GREEN DIMENSION, SAWED, OR TURNED STOCK IN TRANSIT.

If it becomes necessary to ship green dimension, sawed, or turned stock and planks during the late spring and summer months, attention must be paid to the cleanliness and ventilation of such material while in transit.²⁵

Cattle, vegetable, or ventilated box cars which have been previously cleaned are to be preferred for small stock. In ventilated box cars the end doors should be cleated open. If only box cars of the ordinary type are available, the material should be piled according to methods similar to the one shown in figure 22. In the case of spokes and sawed billets, a cross-piled foundation, four to six courses high, is recommended in addition to the directions given (figs. 23 and 24).



FIG. 23.—Artillery spokes "ricked" in a box car. Elm strips one-half inch by $1\frac{1}{2}$ inches used between the courses.

When doors of box cars are loosely boarded up (fig. 25) or cleated open (figs. 9 and 22), it is recommended that they be spiked, that the bill of lading bear an indorsement to the effect that the doors were left open and cleated at the request of the shipper, and finally that

²⁵ The directions given under "Provisions for the proper ventilation of stock in transit," page 23, apply here.

a notice similar to that devised by one of the wheel companies and cited in Bulletin No. 30 of the wood-stock committee²⁰ be nailed to the car, reading as follows:

TAKE NOTICE.—Do NOT CLOSE DOORS.—The lumber in this car is green and is carefully cross piled that there may be good circulation of air through the stock. The doors are left partly open and cleated by the shipper upon request of the consignee. If the doors are closed the stock will be liable to damage in transit.

Should this car break down in transit, making it necessary to transfer the stock to another car, it should be stacked in the car in the same manner and doors left open in the same way.

The use of box cars is usually demanded by those in charge of bending mills where green rim stock is to be shipped. These cars expose the stock to less damage from checking. Unless attention is paid to stripping or some method of piling so as to insure ventilation, however, molding and sap-staining may result. One method used for the piling of rim strips in cars is shown in figure 26.



FIG. 24.—Artillery spokes "ricked" in a box car. A cross-piled base, strips, and open-boarded doorway are important details in the provision for proper ventilation of the stock while in transit.

SUMMARY.

It is evident that the prevention of sap-stain, mold, and incipient decay in green material, and in vehicle stock in particular, lies in a combination of remedial factors, the following being especially important: Care in the selection of raw stock in order to obtain, if possible, material free from fungous infections; expedition in the movement of raw stock from the felling of the logs to that time in the process of manufacture when the material becomes sufficiently dry to resist the attacks of fungi; provision at all times for ample ventilation of the stock that it may quickly become at least surface dried, thus making it difficult for the fungous spores to obtain from the exposed sapwood the moisture necessary for germination;

²⁰ National Implement and Vehicle Association and other Vehicle and Vehicle Parts Manufacturers. Information Division of the Wagon and Vehicle Committee and the Wheel Manufacturers' War Service Committee. Wood Stock Committee. Sap-stain and mold in transit. Nat. Implement and Vehicle Assoc., etc., Bul. 30, 5 p. 1918. A. B. Thielens, chairman. Typewritten.

the kiln drying of the stock wherever possible and whenever the cost will permit; and in special cases steam treatment or the use of anti-septic dips, followed by proper piling to insure ample ventilation.

It must be continually borne in mind that none of these is by itself a sovereign remedy. Preservative dips or steam treatment were not in themselves, under the emergency manufacturing conditions incident to the war, by any means sufficient to control molding of green stock when close piled in storage warehouses or while in transit in box cars.



FIG. 25.—A box car loaded with spokes and ready for shipment. Spaces of $1\frac{1}{2}$ inches are left between adjacent boards nailed across the doorways to allow for ventilation of the stock while in transit.

In connection with this investigation, it should also be borne in mind that we are dealing with three distinct groups of fungi, namely, the molds, staining organisms, and true wood-destroying organisms, the antiseptics being more efficient against the last two groups than

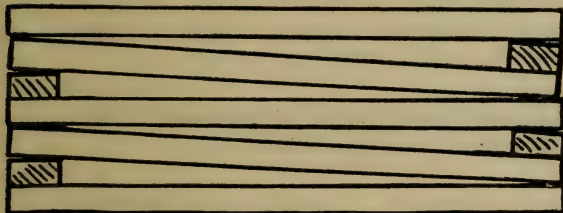


FIG. 26.—Zigzag method of piling rim strips in box cars.

the first. As far as is known, neither molds nor staining fungi cause any appreciable diminution in the strength of timber and hence are unimportant in vehicle manufacture from the standpoint of strength and probably durability. The staining fungi can be controlled to a certain extent by the intelligent use of antiseptics and possibly by steaming, and it seems reasonable, in the light of experience, to suppose that the development of wood-destroying fungi can also be prevented.

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PROFESSIONAL PAPER

May, 1922

STUDIES OF CERTAIN FUNGI OF ECONOMIC IMPORTANCE IN THE DECAY OF BUILDING TIMBERS, WITH SPECIAL REFERENCE TO THE FACTORS WHICH FAVOR THEIR DEVELOPMENT AND DISSEMINATION.

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INTRODUCTION.

There is no means of estimating the total annual loss occasioned by fungi which attack timbers in buildings, but from the evidence at hand it is certain that this loss is very large. This is particularly true in textile mills, paper mills, and canning factories, in which high

¹The writer wishes to acknowledge his indebtedness in connection with these studies to Prof. L. R. Jones, of the department of plant pathology of the University of Wisconsin, for his interest, encouragement, and criticisms; to Mr. C. J. Humphrey, of the Office of Investigations in Forest Pathology, Bureau of Plant Industry, Madison, Wis., under whose immediate direction this work was undertaken, for general supervision, facilities, and criticisms; and to Mr. F. J. Hoxie, engineer and special inspector for the Associated Factory Mutual Fire Insurance Companies of Boston, Mass., for courtesies tendered in connection with mill investigations and for the loan of photographs.

humidities and moderately high temperatures prevail throughout the year. Such conditions provide a very favorable environment for the development of wood-decaying fungi, and this condition is aggravated by the quality of timber which has been on the market in recent years. The timber formerly used in mill construction consisted in many cases of white pine and white oak, both of which are highly durable woods. In more recent years, however, these timbers have been supplanted largely by southern yellow pine, spruce, and hemlock. High-grade resinous longleaf pine has given good service under exacting conditions, but the inferior grades of pine, often of more rapid growth and frequently containing a high percentage of sapwood, have not proved satisfactory in parts of buildings where the conditions are favorable for decay. Likewise, spruce and hemlock have given poor service under similar conditions. Furthermore, such timbers may be left in the open for protracted periods, exposed to the weather and infection by fungi, or may be put in buildings in a partially seasoned condition, and after a short period replacement is necessary, involving not only the direct expense of repairs but also **loss of operating time.**

Hoxie (24, p. 2)² reports that 30 cases of rot of greater or less magnitude have come to his attention within three years. He states that "several million feet of lumber were involved, and in some of the worst cases the safety of important structures was menaced. * * * The direct money loss to Mutual members (Associated Factory Mutual Fire Insurance Companies, Boston, Mass.) * * * is undoubtedly many thousand dollars each year, in addition to the increased life and fire hazard from loss of strength and greater combustibility of rotting structural timbers."

The following specific examples from Hoxie's records may be of interest to show the magnitude of the loss. In a Connecticut mill the roofs of weave sheds, built in 1906 and 1909, were so seriously rotted in 1916 that it was estimated that 40,000 feet of plank would be necessary for repairs. The older roof in many places was not safe to walk upon and had settled so that there were hollows supported practically only by the tarred paper. In one Massachusetts cotton mill built in 1900, 85 per cent of the roof planking and a large proportion of the floor supports had rotted and had been replaced by hemlock, in some cases twice between 1908 and 1914. It was found that hemlock, put in green, lasted about two years. It was estimated that over 1,000,000 feet of lumber had been used in the construction of this mill in 1900, at a cost of \$30,000, and the re-

² The serial numbers in parentheses (*italic*) refer to "Literature cited" at the end of this bulletin.

placements during the four years prior to 1914 required about 240,000 feet of lumber at a cost of more than \$6,100. In another Massachusetts cotton mill, one weave shed, built in 1910, by 1916 was affected with decay throughout, and in another shed in the same mill parts of the roof were replaced in 1914, 1915, 1916, and 1917, necessitating the use of 1,000,000 feet of lumber in 1916 and 30,000 feet the next year. A Canadian mill, built in 1908 with beams of supposedly "first-class Georgia longleaf" pine, was thoroughly rotted by 1911, and the beams were replaced by steel.

Blair (2) gives some similar data with regard to the decay of paper-mill roofs. He found that of 80 mills visited, 12 had made renewals just prior to 1920, 17 were to make renewals in 1920, and 24 others would be compelled to make renewals within a short time after that date. Of the roofs which were being replaced in 1920 the service had been 5 to 19 years, with an average of 8 to 10 years.

The foregoing data show that considerable pecuniary losses were occasioned by the action of decay-producing fungi in mills, even when the prices of lumber and labor were comparatively moderate. With the recent high cost of both these factors, the figures become much more impressive. In one Massachusetts cotton mill replacements made during the summer of 1920 in the roof of a weave shed approximately 1,000 by 300 feet cost the owners between \$100,000 and \$125,000.

In Europe the problem of decay in buildings is of long standing and has received considerable attention. Much has been written from several points of view upon the decay caused by *Merulius lacrymans*, including the engineering and legal as well as the mycological and biological factors. Also, the decays caused by *Coniophora cerebella*, *Poria vaporaria*, and species of *Lenzites* have been particularly studied. In this country the study of timber decay in buildings on a comprehensive scale is only beginning, and thus far the work has largely been confined to *Merulius lacrymans* and its relatives and to *Coniophora cerebella*. In mills and other structures in which conditions favorable for fungus growth prevail, other organisms probably do more damage than these, but have as yet received little attention as structural-timber destroying organisms.

Because of the practical importance of the decays caused by these other fungi in textile mills, etc., the writer has undertaken to make some preliminary studies upon certain of them (*Lenzites sepiaria*, *L. trabea*, *Trametes serialis*, *Fomes roseus*, and *Lentinus lepideus*), especially with regard to certain physiological relations of the mycelium, basidiospores, and secondary spores where they occur. Within the time and facilities at his disposal, as much attention as possible has been paid to those factors influencing the intramural dissemination of these forms.

Lenzites sepiaria has been studied as a destroyer of coniferous timbers in buildings by Falck (15) in Europe and out of doors by Spaulding (58) in this country. Its importance in the destruction of mill roofs was suspected by Hoxie (24) in 1915, and since then he and others, including the writer, have found it fruiting quite commonly and doing much damage in such places. (Pl. I, figs. 1 and 2.) *Lenzites trabea* has been reported by Blair (1) as destroying weave-shed roofs. This species, though usually found upon hardwoods in nature, probably occurs more commonly and is more destructive to coniferous lumber under mill conditions than has yet been reported. The writer has found it fruiting upon yellow pine and spruce roofs. (Pl. I, figs. 3 and 4.)

Trametes serialis has been found upon some of the more badly decayed roofs along with other fungi (Pl. I, fig. 5; Pl. II, figs. 1 and 2), but within buildings it is usually upon basement timbers. This fungus generally occurs in the resupinate form and also forms abortive structures.

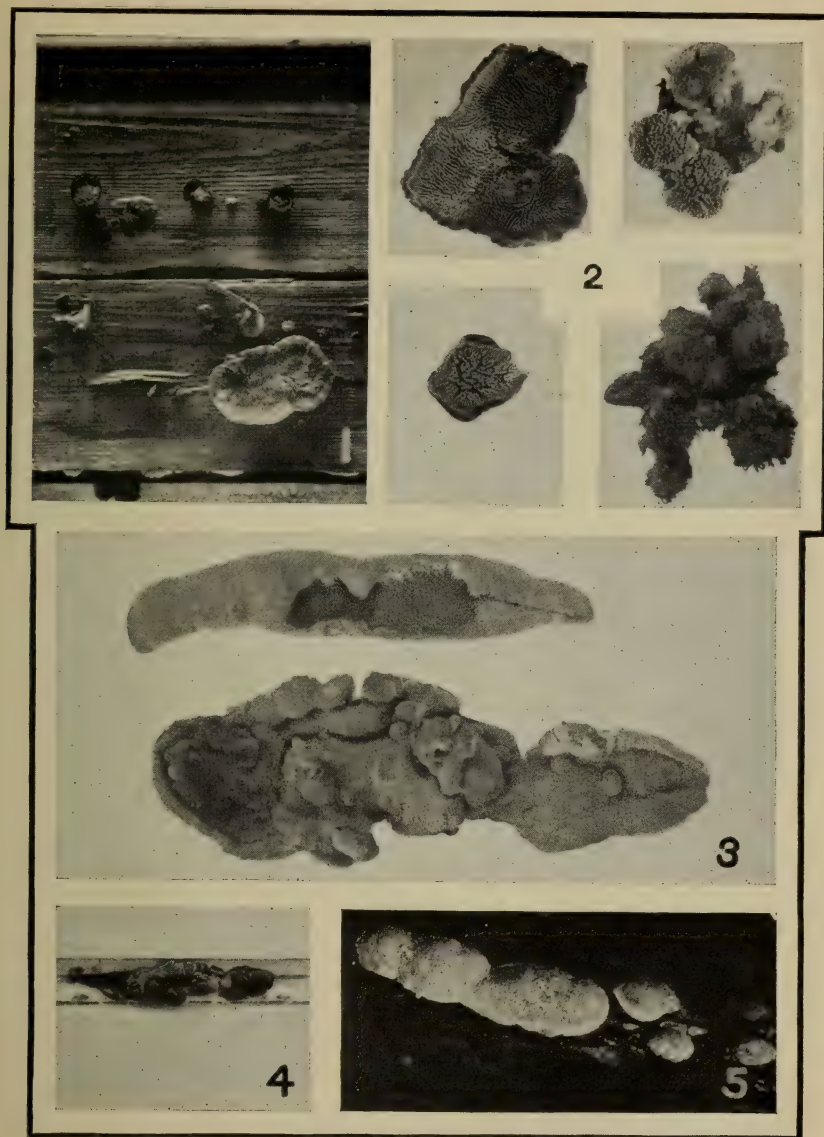
Fomes roseus is found within mills upon beams in moist basements (Pl. II, fig. 5). The annual form is the one of common occurrence, and whether or not the perennial form also occurs is not certain. Many mycologists consider the annual form as a distinct species, *Trametes carnea*.

Lentinus lepideus has been found upon roof timbers under very moist conditions and in basements (Pl. II, figs. 3 and 4). It also occurs in Europe on building timbers (cf. Mez, 35; Falck, 17.) Its destructiveness to structural timber in the open is well known.

BASIDIOSPORES.

SOURCES OF BASIDIOSPORE MATERIAL.

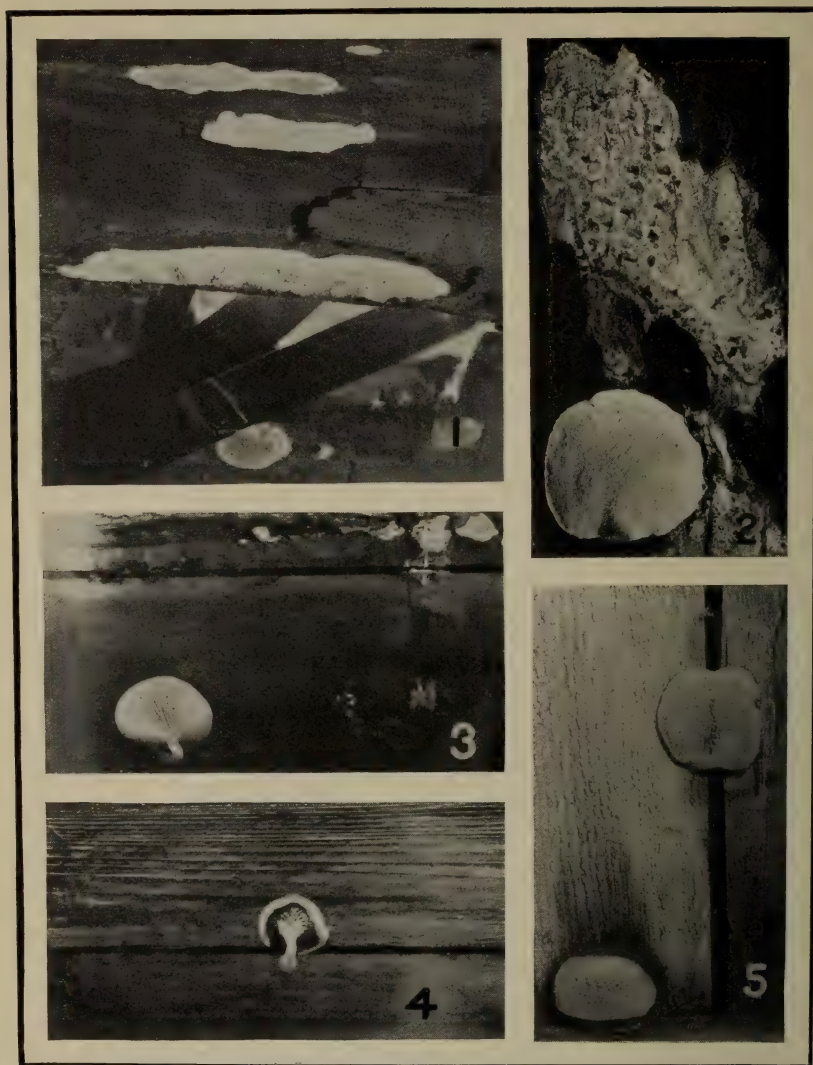
The basidiospores used were obtained for the most part from fruit bodies collected in the field. Those of *Lenzites sepiaria* were from various collections in Wisconsin. The spores of *Lenzites trabea* were obtained from fruit bodies upon pulpwood bolts, collected in Pennsylvania, by F. J. Hoxie. The basidiospores of *Trametes serialis* were obtained from fructifications on some rotten timbers (removed on account of decay) from the pulp-and-paper section in the Forest Products Laboratory and placed in the forest-pathology greenhouse. From two or three small sporophores formed in November, 1919, sufficiently large numbers of spores were obtained to last through two winters of experimentation. Sporophores of the annual form of *Fomes roseus* were collected upon tamarack (*Larix laricina*) logs in Wisconsin and red spruce (*Picea rubens*) in New Hampshire. The spores of *Lentinus lepideus* were obtained from sporophores collected by Mr. Hoxie in a cotton mill in Massachusetts.



FUNGI OF ECONOMIC IMPORTANCE IN THE DECAY OF BUILDING TIMBERS.—I.

(Figures 1, 2, and 5 were photographed by F. J. Hoxie.)

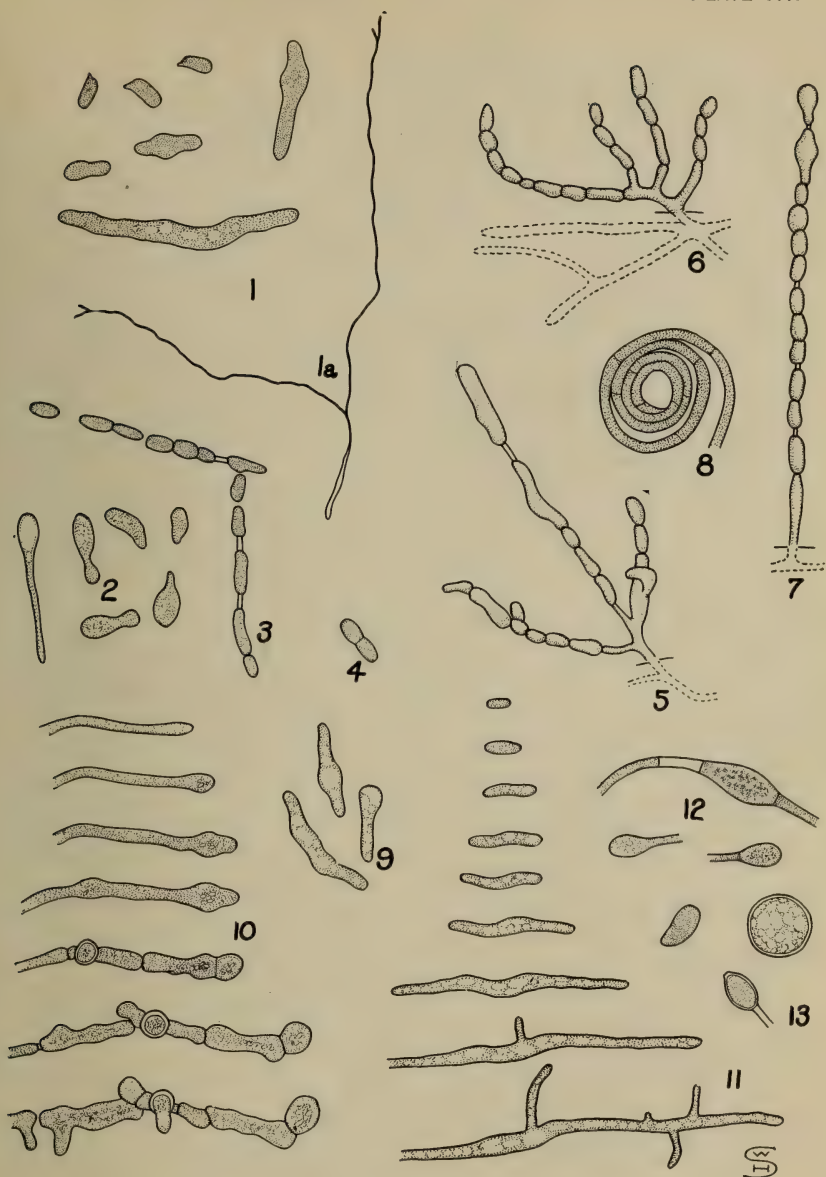
FIG. 1.—Sporophores of *Lenzites sepiaria* on planks of weave-shed roof which was originally sheathed. ($\times \frac{1}{4}$.) FIG. 2.—Sporophores of *Lenzites sepiaria* from cotton-mill roof. ($\times \frac{3}{4}$.) FIG. 3.—Sporophores of *Lenzites trabea* from cotton-mill roof, same as that shown on roof plank in figure 4. ($\times \frac{9}{10}$.) FIG. 4.—*Lenzites trabea* fruiting body between planks of cotton-mill roof. ($\times \frac{1}{4}$.) FIG. 5.—*Trametes serialis* fruiting upon planks of a roof which was originally sheathed. ($\times \frac{1}{4}$.)



FUNGI OF ECONOMIC IMPORTANCE IN THE DECAY OF BUILDING TIMBERS.—II.

(Photographed by F. J. Hoxie.)

FIG. 1.—*Trametes serialis* fruiting around belt hole in a weave-shed floor. ($\times \frac{1}{2}$.) FIG. 2.—Fruit body of *Trametes serialis* on planking in basement of cotton mill. ($\times \frac{1}{2}$.) FIGS. 3 and 4.—Fruit bodies of *Lentinus lepideus* on planking of weave-shed roof which was originally sheathed. ($\times \frac{1}{2}$.) FIG. 5.—*Fomes roseus* fruiting on ceiling planks of basement of cotton mill. ($\times \frac{1}{2}$.)



BASIDIOSPORE STUDIES OF LENZITES SEPIARIA.

($\times 475$, except 1a, which is $\times 67$.)

FIG. 1.—Germinating basidiospores on malt agar. FIG. 1a.—Extent of the growth which may take place before branching begins. FIG. 2.—Germinating basidiospores in distilled water. FIG. 3.—Oidia upon submerged mycelium in agar. FIG. 4.—Septate oidium. FIGS. 5, 6, and 7.—Aerial mycelium almost completely broken up to oidal chains. FIG. 8.—Coil in aerial mycelium of older cultures. FIG. 9.—Germinating oidia. FIG. 10.—Successive stages in formation of oidia and one chlamydospore in submerged mycelium in agar, with germination of the chlamydospore. FIG. 11.—Stages in the germination of a single oidium. FIG. 12.—Stages in the formation of chlamydospores in submerged mycelium. FIG. 13.—Chlamydospores or chlamydosporelike bodies.



BASIDIOSPORE STUDIES OF LENZITES AND TRAMETES.

(X 475.)

FIG. 1.—Germinating basidiospores of *Lenzites trabea* on malt agar. FIG. 2.—Oidia of *Lenzites trabea* from secondary aerial mycelium on malt agar. FIG. 3.—Stages in formation of chlamydospores upon submerged mycelium of *Lenzites trabea* in malt agar. FIG. 4.—Chlamydospores and chlamydosporelike bodies of *Lenzites trabea* upon submerged mycelium in malt agar, one of them germinating. FIG. 5.—Germinating basidiospores of *Trametes serialis* on malt agar. FIG. 6.—Stages in formation of chlamydospores of *Trametes serialis* on malt agar. Note contraction of protoplasm and formation of walls. FIG. 7.—Chlamydospores of *Trametes serialis* from submerged mycelium in malt agar. FIG. 8.—Chlamydospore of *Trametes serialis* on aerial mycelium in malt agar tube, showing old walls. FIG. 9.—Germinating chlamydospores of *Trametes serialis* on malt agar. FIG. 10.—Irregular hypha from tertiary mycelium of *Trametes serialis* at top of agar slant culture. FIG. 11.—Sprouting of clamp of *Trametes serialis*. FIG. 12.—Clamps, anastomosing of hyphae, and other irregularities from agar slant cultures of *Trametes serialis*.



BASIDIOSPORE STUDIES OF FOMES AND LENTINUS.

(X 475.)

FIG. 1.—Germinating basidiospores of *Fomes roseus* on malt agar. FIG. 2.—Germinating basidiospores of *Lentinus lepideus* on malt agar. FIG. 3.—Anastomosing of hyphae, one from clamp, of *Lentinus lepideus*. FIG. 4.—Chlamydospore from aerial tertiary mycelium of *Lentinus lepideus* on malt agar. FIG. 5.—Chlamydospores of *Lentinus lepideus* on submerged mycelium, in malt agar. FIG. 6.—Mature and immature chlamydospores from colored mycelium overgrowing gills of sporophore of *Lentinus lepideus*, collected in a Massachusetts cotton mill. FIG. 7.—Wavy branch from aerial mycelium of malt agar culture of *Lentinus lepideus*. FIG. 8.—Types of anastomosing of mycelium of *Lentinus lepideus* on malt agar. FIG. 9.—Clamps from aerial mycelium of *Lentinus lepideus* on malt agar. FIG. 10.—Basidiospores of *Lentinus lepideus* germinating upon red spruce.

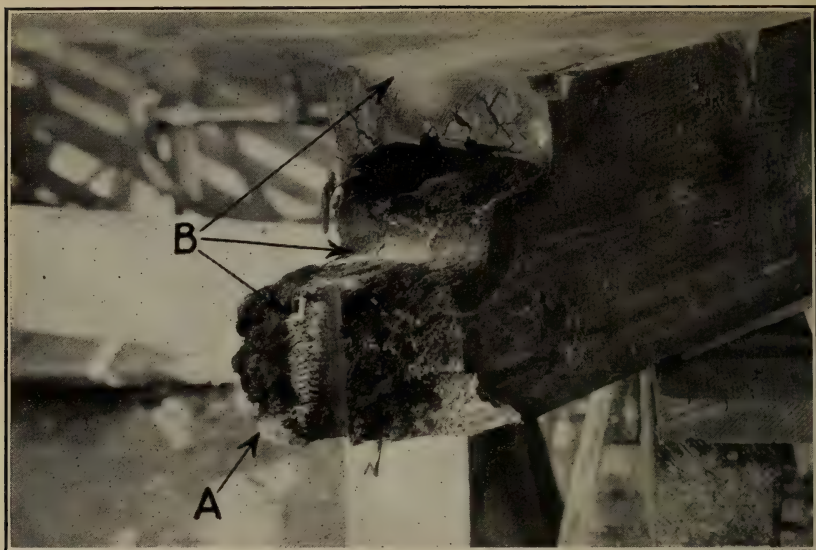


FIG. 1.—DISSEMINATION OF BASIDIOSPORES OF *TRAMETES SERIALIS* BY IMPERCEPTIBLE CURRENTS OF AIR IN A CLOSED PIT.

The sporophore at *A* naturally dropped spores downward, but in the closed pit there were air currents of sufficient magnitude to carry the spores upward to be deposited at points marked *B*. ($\times \frac{1}{5}$.)



FIG. 2.—DISSEMINATION OF *TRAMETES SERIALIS*.

Basidiospores of *Trametes serialis* on the leg of a sow bug caught in condensation water beneath the sporophore in fungus pit at Madison, Wis. ($\times 250$.)

METHODS USED IN THE BASIDIOSPORE STUDIES.

The basidiospores used in the tests were collected and kept on sterilized glass slides, as a rule, although the spores of *Lentinus lepideus* were collected upon sterilized black paper. The spore prints were obtained in the usual way, care being taken to prevent moisture from collecting upon the prints for it was found early in the work that such condensation water affected the viability of the spores. The prints were then preserved in Petri dishes in an ice box in which the temperature was 12° to 16° C., and the relative humidity 40 to 45 per cent. For the general purposes of experimental work the glass slides for spore prints were preferred to the black paper because of ease of manipulation and cleanliness.

All spore germination tests were made upon the surface of agar, usually in Van Tieghem cells. The germination of spores upon the surface of the cooled agar had certain advantages. The question of the oxygen supply available for the spores was obviated. It was easier to count percentages of germinated spores when they were all in one plane. And besides there was no danger of subjecting the spores to unfavorable temperatures, as may be the case when they are introduced into melted agar. A temperature only slightly too high, produced either by a hot needle or hot agar, materially reduces the percentage of germination. For purposes such as drawing, photography, or examination by the higher powers of the microscope, sowings of spores were made upon thin films of agar poured on sterile slides kept in moist chambers under sterile conditions. The agar media used for all experimentation contained 2 per cent of agar with 2½ per cent of malt extract, filtered through filter paper in a Büchner filter and autoclaved 30 minutes at 8 pounds pressure. Occasionally, for the taking of photomicrographs, water agar (malt extract omitted) similarly filtered was used because of its greater transparency. Unless otherwise specified, all germination tests were run in an incubator at 28° C.

GERMINATION OF THE BASIDIOSPORES.

The germination of the basidiospores of the species under consideration presents no features unusual for hyaline hymenomycetous spores. All of them swell more or less in the process. The spores of *Lenzites sepiaria*, *L. trabea*, and *Lentinus lepideus* swell to very little more than the diameter of the germ tube, so that they are not very conspicuous in the thalli of the germinated spores (Pl. III, fig. 1; Pl. IV, fig. 1; Pl. V, fig. 2). *Fomes roseus* spores swell considerably (Pl. V, fig. 1), but those of *Trametes serialis* swell much more (Pl. IV, fig. 5). These latter spores swell to a large globular body of many times the volume of the original spore before the germ

tubes are formed, and the spore is always very conspicuous in the thallus. The germ tubes of *Fomes roseus* have been more vacuolate than those of the other species.

The spores of all species germinate readily upon all nutrient media and upon red spruce (Pl. V, fig 10, for *Lentinus lepideus*). In water the results were as erratic as those reported by other workers with spores of basidiomycetes. The spores germinated in tap water, although the proportion ranged from less than 1 to 55 per cent in distilled water germination took place occasionally (Pl. III, fig. 2, for *Lenzites sepiaria*). The rate of germination was usually low, although sometimes as high as 50 per cent. Even with fresh spores germination could not always be induced in distilled water.

EFFECT OF TEMPERATURE UPON THE GERMINATION OF THE BASIDIOSPORES.

In these studies both percentage and rapidity of germination have been noted. It is interesting to know the rate at which these spores germinate, but of the two criteria percentage would be likely to give the best indication of the effect of various environmental conditions. From the point of view of infection of structural timbers, if a large percentage of spores will germinate over a wide range of temperatures it makes little difference whether it takes three or four days for them to germinate at 10° C. (49° F.) or only 16 hours at the optimum rate of germination. The chances for infection, however, are somewhat greater at the optimum temperatures, because of the somewhat larger number of spores capable of germinating. The percentages given herewith have no absolute value, either for the individual species or for purposes of comparison between species. It is possible that spores collected from different fruit bodies of the same species of different degrees of maturity, from different climatic conditions, and under different conditions of casting might give varying percentage values. It is certain that age is a factor. Hence, that one species should give 75 per cent germination at the optimum temperature and another only 40 per cent does not mean that the spores of the one are inherently more vigorous than those of the other. In the data presented germination is taken to consist in a germ tube at least as long as the swollen spore. The data for the effect of temperature upon germination are given in Table 1 and in figure 1.

For *Lenzites sepiaria* with certain variations tests showed that between 12° and 40° C. (53° and 104° F.) there was little difference as to the effect of temperature upon the percentage of germination if the time element was disregarded. The optimum for rate of germination was between 32° and 36° C. (89° and 97° F.), an optimum somewhat lower than that obtained by Falck. At 40° C. (104° F.) the results varied with the age of the spores. Those a few months

old gave only sparing germination, while fresh ones germinated about as well as at 36° C. (97° F.) but more slowly. Falck (15,

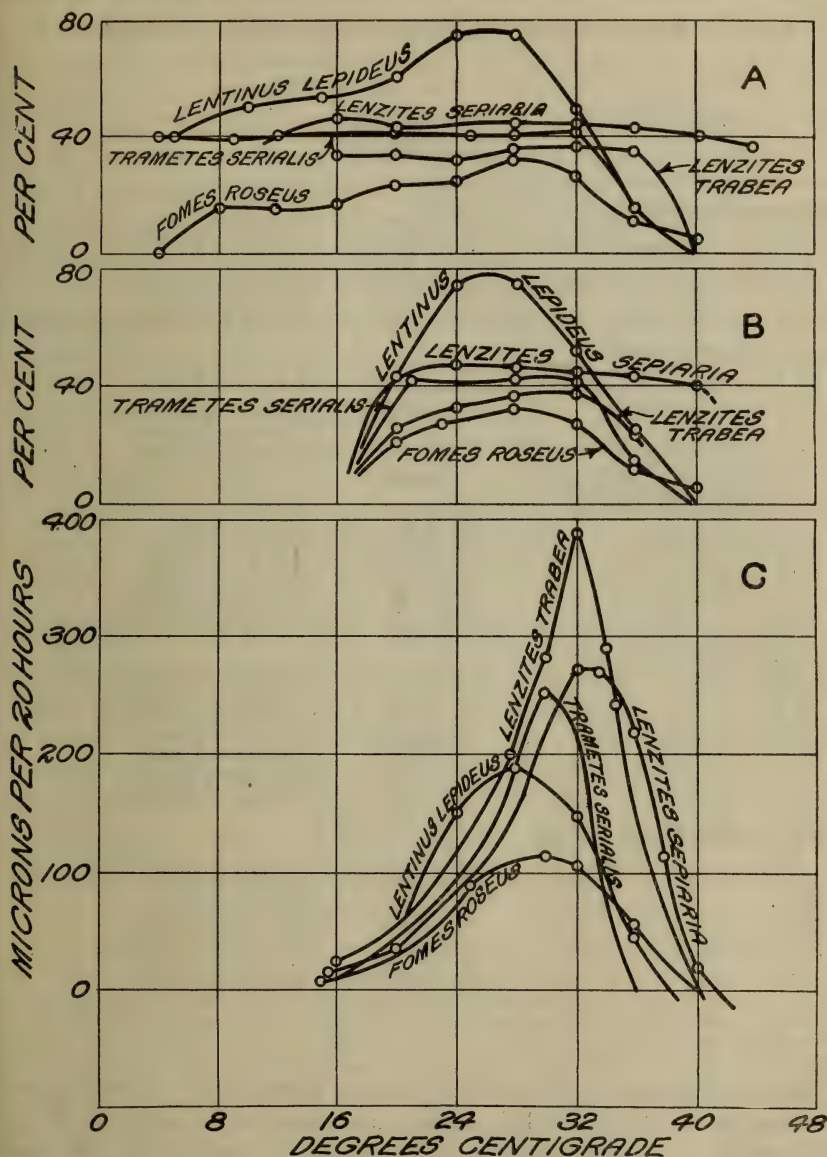


FIG. 1.—Effect of temperature upon the germination of the basidiospores upon malt agar. A, Maximum percentage obtained, disregarding the time element; B, percentage of germination in 20 hours; C, rate of growth of the thalli in 20 hours (shown in microns). These values are not to be considered as absolute for any of the species, nor are they necessarily comparable species with species, but they represent the values obtained with the spores available.

pp. 98-99) found that they germinated at 42° C. (107° F.) but not at 46° C. (115° F.), with most rapid germination at 34° C. (93° F.).

The lowest temperature tried by him was 10° C. (49° F.), and the spores germinated at that temperature.

TABLE 1.—Relation of temperature to the germination of basidiospores.

Species and temperature.	Germination.		
	Per cent.	Taken in—	Rate.
<i>Lenzites sepiaria</i> (spores 3 days old):			
12° C.	40	4 days	Germinated in 2 days.
15° C.	46	do	14 to 18 μ in 20 hours.
20° C.	43	24 hours	30 to 40 μ in 20 hours.
28° C.	45	20 hours	105 to 175 μ in 20 hours.
32° C.	44	do	210 to 350 μ in 20 hours.
36° C.	43	do	180 to 250 μ in 20 hours.
40° C.	40	36 hours	Swelling and beginning of tubes in 36 hours.
<i>Lenzites trabea</i> (spores fresh):			
16° C.	33	3 days	12 to 21 μ in 20 hours.
20° C.	34	48 hours	43 to 73 μ in 20 hours.
24° C.	32	36 hours	90 to 143 μ in 20 hours.
28° C.	36	26 hours	160 to 245 μ in 20 hours.
30° C.			210 to 350 μ in 20 hours.
32° C.	37	26 hours	310 to 450 μ in 20 hours.
36° C.	35	do	175 to 200 μ in 20 hours.
40° C.	(a)	36 hours	Just beginning in 20 hours.
<i>Trametes serialis</i> (spores 8 days old):			
3° C.	40	12 days	7 to 32 μ in 12 days.
9° C.	39	10 days	15 to 25 μ in 8 days.
15° C.	41	6 days	160 to 300 μ in 3 days.
20° C.	41	42 hours	31 to 68 μ in 20 hours.
25° C.	40	24 hours	60 to 80 μ in 20 hours.
28° C.	41	do	87 to 125 μ in 20 hours.
32° C.	43	do	210 to 235 μ in 20 hours.
36° C.	15	do	Just beginning in 20 hours.
40° C.	0	3 days	
<i>Fomes roseus</i> (spores fresh):			
4° C.	1	1 month	Germination in 1 month.
8° C.	15	9 days	Germination in 9 days.
12° C.	15	3 days	Germination in 3 days.
16° C.	17	do	Just beginning in 20 hours.
20° C.	23	2 days	12 to 36 μ in 20 hours.
24° C.	24	24 hours	57 to 98 μ in 20 hours.
28° C.	33	do	98 to 120 μ in 20 hours.
32° C.	26	do	84 to 121 μ in 20 hours.
36° C.	12	do	Just beginning in 20 hours.
40° C.	5	do	
<i>Lentinus lepideus</i> (spores 7 months old):			
5° C.	40	10 days	Thalli up to 43 μ in 23 days.
10° C.	50	5 days	25 to 40 μ in 5 days.
15° C.	54	3 days	50 to 80 μ in 5 days.
20° C.	60	2 days	43 to 61 μ in 20 hours.
24° C.	75	21 hours	133 to 174 μ in 20 hours.
28° C.	75	18 hours	150 to 221 μ in 20 hours.
32° C.	50	16 hours	124 to 178 μ in 20 hours.
36° C.	6 to 25	24 hours	42 to 60 μ in 20 hours.
40° C.	0		Just beginning in 20 hours.

a Less than 1 per cent.

The basidiospores of *Lenzites trabea* germinated in small percentages at 40° C. (104° F.), at high percentages from 24° to 32° C. (75° to 89° F.), and most rapidly between 28° and 32° C. (82° and 89° F.).

The spores of *Trametes serialis* germinated at the lowest temperature tried, 3° C. (36° F.), but not at 40° C. (104° F.). The general optimum for percentage was between 20° and 32° C. (68° and 89° F.), with the most rapid germination between 30° and 32° C. (86° and 89° F.).

Fomes roseus spores germinated most rapidly between 28° and 32° C. (82° and 89° F.), while the percentage was highest between 24° and 32° C. (75° and 89° F.).

For *Lentinus lepideus* the largest percentage of germination was between 25° and 28° C. (76° and 82° F.), although 40 per cent germinated in 16 hours at both 20° and 32° C. (68° and 89° F.). The percentage for the lower temperatures down to 5° C. (40° F.) was 40 to 50 per cent. These spores germinated in 10 hours at 28° C. (82° F.) and in 18 to 20 hours at 24° C. (75° F.).

Falck (16, p. 258) has suggested that the percentage optimum for germination of basidiospores is to a certain extent a matter of simultaneous germination, and that as the optimum is approached there is a greater number of simultaneously germinating spores. Inasmuch as all the spores do not germinate at the same time, particularly at the lower temperatures, care should be taken to give the viable spores opportunity to germinate. According to Falck, the more favorably situated spores germinate first, but there is also the possibility that the less favorable temperatures affect the protoplasm of the individual spores differently and thus cause differences in rapidity of germination. In the case of *Lentinus lepideus* (Table 1) at 5° C. only a small percentage had germinated in 5 days, 30 per cent in 8 days, and 40 per cent in 10 days. Care must be taken also that the percentage counts are not made at intervals too great to keep track of what is going on at the lower temperatures. Whereas basidiospores of *L. lepideus* germinated 30 per cent in 8 days and 40 per cent in 10 days at 5° C., in 23 days in the same set of duplicate hanging drops only 22 per cent of living thalli could be counted. The explanation seems to be that of the 40 per cent which had germinated, a certain number of the germinated spores could not stand the low temperature and had died and become invisible on the agar substrate.

EFFECT OF LIGHT UPON THE GERMINATION OF THE BASIDIOSPORES.

Hoffmann (21, p. 32) found that spores of *Agaricus campestris* germinated sooner in the light than in the dark and that bright sunlight did not hurt the spores of several imperfect fungi and some rusts. Ferguson (19, p. 21) found, however, that the spores of *Agaricus campestris* would not germinate in direct sunlight or in diffused light in four weeks, even under the special conditions furnished by her for the germination of these refractory spores. In the experiments by Buller (8, pp. 24-26) spores of *Daedalea unicolor* and *Schizophyllum commune* germinated after exposure to direct sunlight for periods up to eight hours, but the germination of these was slower than of those kept in the dark, and the percentage of

germination was lower. In three days the mycelium from the spores kept in the dark was more advanced than that from the spores exposed to the sunlight. Rhoads (47, p. 66) noted no difference in the time required for the germination of the spores of *Polyporus pargamensis* in the presence or absence of diffused light.

The writer tested the action of both diffused light and direct sunlight upon dry spore prints for a possible killing effect and upon spores on agar during germination for a possible inhibiting effect. Duplicate spore prints upon slides or agar plates with spores for germination were placed side by side in the light, supported upon a nonconducting frame, with one of the pair inclosed in a box made light-tight and yet allowing for ventilation, in order to prevent the heating of the slides or Petri dishes. Experiments upon the effect of diffused light acting during germination were started in the early morning and allowed to run until the next night, in order to have the spores under the influence of light while starting to germinate and to obtain the maximum amount of daylight.

It was found that two days of diffused light in an east window during the winter had no appreciable effect upon the percentage of germination or upon the rapidity of germination, although it hindered the subsequent growth of the thalli somewhat.

It was found also that diffused light acting upon dry spore prints for 10 days had no appreciable effect on the viability of the spores.

Direct sunlight acting upon the basidiospores upon agar inhibited germination during exposure, as compared with controls. Spores exposed to direct sunlight for one day would germinate upon being set aside in the dark, but those exposed for two days showed little or no germination.

The tests on the killing effect of direct May and June sunlight upon dry spores were carried on chiefly with the basidiospores of *Lenzites sepiaria* and *L. trabea*, with two tests on the spores of *Trametes serialis* and *Lentinus lepideus*. When the tests were properly checked so as to obviate as far as possible the effect of atmospheric conditions, the results were as consistent as could be expected.

In general, it was found that one day of exposure did not affect the viability of the spores materially. An exposure of two days usually reduced the percentage of germination considerably, sometimes entirely, while three days' exposure usually killed most of the spores. Only those tests were considered in which the control slides showed unreduced germination at the end of the test, for it was found, as will be shown later, that certain atmospheric conditions greatly reduced the viability of the spores.

Two experiments were tried to see if the germ tubes showed any phototropic reactions. The slides of Van Tiegham cells were placed

in a photographic plate box with a slit 5 millimeters wide cut in one of the narrow sides. The box was set up with the slides inside, the slit toward an east window. In the first test the cells were inoculated at night and examined in 24 hours. In the second the inoculations were made in the morning and examined in 24 hours. In neither set did the germ tubes of any of the four species, *Lenzites sepiaria*, *L. trabea*, *Trametes serialis*, *Lentinus lepideus*, show any phototropic response. The tubes pushed out of the ends of the swollen spores as usual, and their subsequent course was as irregular as in the dark or in diffused light, where checks were placed.

RETENTION OF THE VIABILITY OF THE BASIDIOSPORES.

Falck (15, pp. 99-100) expressed the opinion that in nature the length of time the spores of wood-destroying fungi could retain their viability was a matter of little moment, inasmuch as most of them had the ability at least to hold over the longest period of drought. Rumbold (49, p. 102) found that 0.25 per cent of the spores of *Coniophora cerebella* germinated after one year and six months under laboratory conditions. Falck (15, p. 100) reported that the spores of *Lenzites sepiaria* 6 months old germinated like fresh spores, but from that time there was a steady decrease in the percentage of germination. In a year and seven months only a very few germinated, and none in two years. The spores of *Merulius lacrymans* he found (16, p. 234) to be longer lived. Spores 1 year old germinated normally; after three years 25 per cent germinated; and after five or six years spores sprayed with 2 per cent malic acid, dried immediately, and then put in a moist chamber at 15° C. gave some germination. Rhoads (47, p. 70) showed that the spores of *Polyporus pargamensis* kept on waxed paper in a desk in a warm room remained viable for 10 months, but not for 12. At the end of that time there was swelling, but no germination.

The question as to the maximum period of retention of vitality resolves itself into how best to preserve spores under laboratory conditions. It has been shown by Falck (15, p. 100) and Möller (36, p. 38) that spores are best preserved when taken dry and kept dry, and that spores in a moist atmosphere soon deteriorate. Thick prints also undoubtedly keep better than thin ones. Just what combination of dryness and temperature is more favorable for prolonging the life of the spores is not certain. The writer has kept spores best in an ice box, where the temperature was found to be 12° to 15° C. and the relative humidity 40 to 45 per cent. A very humid atmosphere is harmful, as are also very dry conditions at higher temperatures. Whether very dry and cool conditions would be better than a moderate amount of moisture in the air at the same temperature is not known.

The longest periods during which any spores of the species studied have given germination are shown in Table 2.

TABLE 2.—*Maximum period of retention of viability of the basidiospores of Lenzites sepiaria, Lenzites trabea, Trametes serialis, Fomes roseus, and Lentinus lepideus.*

Species and source of spores.	Period of retention of viability.		Germination.
	Dates.	Spores germinated after—	
<i>Lenzites sepiaria</i> : Madison, Wis., November, 1917.	Apr. 13, 1918, to Feb. 10, 1921.	2 years 10 months <i>a</i>	25 per cent.
<i>L. trabea</i> : Cotton mill, Centerville, R. I., February, 1920.	February, 1920, to February, 1921.	1 year <i>a</i>	60 per cent.
<i>Trametes serialis</i> : Madison, Wis., November, 1916.	November, 1916, to February, 1921.	4 years 3 months <i>a</i>	2 per cent.
<i>Fomes roseus</i> : Wisconsin, June, 1917, on tamarack (<i>Larix</i>).	June, 1917, to December, 1918.	18 months <i>b</i>	Few in thousands.
Minnesota, June, 1919, on <i>Prunus</i> .	June, 1919, to Feb. 10, 1921...	1 year 8 months <i>a</i>	Less than 1 per cent.
<i>Lentinus lepideus</i> : Cotton mill, New Bedford, Mass., July 5, 1918.	July 5, 1918, to Feb. 10, 1921..	2 years 7 months <i>b</i>	Do.

a These figures refer to the last tests; further tests may show that these spores survived longer periods.

b These spores gave no germination in 20 months.

VIABILITY OF BASIDIOSPORES DRIED AT DIFFERENT TEMPERATURES.

Because of the lack of sufficient quantities of basidiospores, tests upon the effect of drying are neither complete nor entirely satisfactory, because only one series has been conducted. It is to be expected that the age of the spores will make some difference in their resistance to drying and that, as pointed out previously, individual casts of spores may vary, hence the tests here reported are only indicative. For example, it will be noted (Table 3) that spores of *Trametes serialis* 2 years old succumbed sooner at 28° C. (82° F.) than at 32° C. (89° F.).

At 28° and 32° C. the spores of *Trametes serialis* and *Lentinus lepideus* of the ages given ceased to germinate after an exposure of about 10 weeks to dry incubator conditions. At 36° C. (97° F.) it took about a month to kill all or most of the spores.

At 40° C. (104° F.) it will be noted (Table 4) that in one week there was a decided drop in the percentage of germination of the spores of the three species tested. Those of *Fomes roseus* did not survive one week at 40° C. In two months, however, the spores of *Lenzites sepiaria* were not all killed, nor those of *Trametes serialis* in six weeks. These spores were fresh, while those in the tests at 36° C. were not absolutely fresh.

TABLE 3.—*Effect of drying at different temperatures upon the germination of basidiospores of Trametes serialis and Lentinus lepideus.*

Drying temperature.	Trametes serialis (spores 2 years old).			Lentinus lepideus (spores 5 months old).		
	Period.	Germination (per cent).		Period.	Germination (per cent).	
		Dried.	Check.		Dried.	Check.
At 28° C. (82° F.).....	Beginning.....	50	50	Beginning.....	50	50
	1 week.....	30	50	2 weeks.....	51	50
	2 weeks.....	18	50	4 weeks.....	24	49
	4 weeks.....	1	50	6 weeks.....	28	50
	6 weeks.....	0	50	8 weeks.....	14	52
	.....	.....	.....	9½ weeks.....	0	50
At 32° C. (89° F.).....	Beginning.....	50	52	Beginning.....	50	50
	1 week.....	1	48	2 weeks.....	53	49
	2 weeks.....	1	51	4 weeks.....	22	48
	4 weeks.....	1	51	6 weeks.....	17	51
	6 weeks.....	1	50	8 weeks.....	5	42
	9½ weeks.....	0	0	9½ weeks.....	0	51
At 36° C. (97° F.).....	Trametes serialis (spores 10 days old).			Lentinus lepideus (spores 7 months old).		
	Beginning.....	99	99	Beginning.....	32	32
	10 days.....	8	45	10 days.....	20	21
	18 days.....	1	20	18 days.....	3	20
	28 days.....	0	20	28 days.....	(¹)	20
						

¹ Less than 1 per cent.

TABLE 4.—*Effect of drying basidiospores of Lenzites sepiaria, Trametes serialis, and Fomes roseus at 40° C.*

Drying temperature.	Lenzites sepiaria (spores fresh).			Trametes serialis (spores fresh).			Fomes roseus (spores 5 months old).		
	Period.	Germination (per cent).		Period.	Germination (per cent).		Period.	Germination (per cent).	
		Dried.	Check.		Dried.	Check.		Dried.	Check.
40° C. (104° F.)..	Beginning.....	38	38	Beginning.....	76	75	Beginning.....	38	30
	1 week.....	13	39	1 week.....	14	75	1 week.....	0	26
	20 days.....	8	39	6 weeks.....	7	70	.....	.....	.....
	2 months.....	3	38	.....	.....	.....	.....	.....	.....

EFFECT OF ALTERNATE WETTING AND DRYING UPON THE VIABILITY OF THE BASIDIOSPORES.

In removing spores from a spore cast on a glass slide, a large number of the spores dislodged from the slide by the water are left behind. From the point of view of economy of material the question naturally arose as to whether or not these spores wet once and allowed to dry out again were capable of normal germination. A number of tests made upon different lots of spores of varying ages from fresh ones to those a few weeks old seem to show that alternate wetting and drying reduce the percentage of viable spores. In one

case the reduction in the percentage of germination was only from 48 to 37 per cent. In others, it was from 70 to 20 or 30 per cent. In most of the tests, however, the reduction was more pronounced, resulting in no germination or only 2 to 5 per cent. The lack of uniformity in results is probably to be explained by differences in the condition of the spores, length of time they remained wet, and time taken to dry.

It was found in the preliminary experiments of the effect of light upon germination that spore prints left out of doors over night, even though protected from falling water, lost their viability after one or two nights and days. Similar spores retained their normal viability, however, when protected over night in a closed desiccator (without drying chemical). Spores of all five fungi studies behaved in the same manner. The explanation is probably to be found in the diurnal changes of atmospheric humidity.

OBSERVATIONS ON THE CASTING OF THE BASIDIOSPORES.

Buller (8, p. 111) has shown that fruit bodies of *Lenzites sepiaria* can be revived and made to cast spores after four months of drying. Falck (15, p. 66) revived them after one year and nine months of drying. The writer collected some sporophores of this plant from prostrate white pine in Wisconsin in June, 1919. The weather had been sufficiently moist to allow the formation of an abundance of sporophores and it is not known how long any of them had been casting spores. The collections were taken inside and left for a day. They were then moistened over night and placed upon glass slides the next day for spore casting. At night the prints were collected and the sporophores allowed to dry on a table in the room until the night of the second day following, when they were again moistened for another cast the next day. With this rotation of 48 hours of drying in the room, 12 hours of wetting, and then 12 hours of casting, spore prints were obtained six times. The seventh time the sporophores failed to produce visible prints. Several sporophores collected when frozen in November, 1919, and then kept in an ice box for one month were treated in a similar manner in the laboratory. Visible casts were obtained four or five times from single sporophores, even through the summer of 1920.

Sporophores of *Lenzites sepiaria* kept in the laboratory were revived after 15 months and usable prints obtained, but the same ones would not revive after two years. Sporophores which had overwintered out of doors during 1919-20 (one set in Providence, R. I., and the other in northern Vermont) were made to cast spores in early March and April, 1920.

Sporophores of *Lenzites trabea* have been revived after six to nine months, but repeated castings have not been obtained from the same

sporophores. Sporophores collected near Providence which had overwintered were made to cast spores abundantly in April, 1920.

The fruit bodies of *Trametes serialis* studied were those, already referred to, which were formed in the fungus pit in the forest-pathology greenhouse at Madison, Wis. This fungus fruited on the timbers each fall from 1916 to 1919. It is not known whether fruiting occurred at other times. The sporophores were few in number and the total hymenial surface never exceeded 150 square centimeters. These small fruit bodies, however, liberated large numbers of spores. Figure 1 of Plate VI shows visible prints from one small one during two or three days on a vertical surface where the hymenial surface was not large, and it is likely that only a small part of the spores cast were caught on the surfaces shown. In a single day resupinate sporophores cast thick crusts of spores on glass slides and continued to do so for several days. All of the basidiospores of *Trametes serialis* used in this work for three winters came from heavy casts made in the fall of 1916. Three fruit bodies formed in November, 1919, were kept under observation in order to obtain some idea as to the length of the casting period. Fruiting was first noted on November 18 and casting had already begun. It continued for 15 consecutive days.

These fruiting bodies of *Trametes serialis* were formed in the dark. The largest one was kept in the dark for the whole period of 15 days, and the two smaller ones were put in a moist chamber in the light in the laboratory. Spores were cast abundantly in both places. On the fifteenth day the sporophores began to turn brown at the edges and shrivel up, although in an atmosphere practically saturated, and these parts became attacked by molds. On the next day the browning and shriveling had proceeded farther and the molds had spread. The simultaneous cessation of casting and encroachment of molds was striking, as was the absence of molds on the delicate hymenia during the 15 days of sporulation under very humid conditions. The same phenomenon was observed in the tests on the casting of spores by *Lenzites sepiaria*, as molds did not make their appearance until after the sporophores had ceased to cast spores. The spent fruit bodies of *Trametes serialis* left in the fungus pit soon disappeared. When dried artificially, they became very thin, fragile, and distorted, but in the pit they disintegrated through attack by molds and consumption by sow bugs.

The writer has never succeeded in obtaining basidiospores from the perennial form of *Fomes roseus*. From the annual form spores are usually cast sparingly. In the laboratory visible prints have been obtained only occasionally. Attempts to obtain prints out of doors were made at Crawfords, N. H., in September, 1919, during a pro-

tracted period of moist weather, but efforts with many sporophores at different locations resulted in little success. Sporophores of the annual form of *F. roseus* were revived to cast a few spores after 20 months in the laboratory.

No data are at hand relative to the length of the spore-casting period of *Lentinus lepideus*. Sporophores of this fungus will sometimes revive in moist atmosphere after having been kept dry a few months (six months at least) and will cast spores. The chief difficulty in obtaining prints is that molds growing on the fleshy pilei contaminate them. A single fruit body will liberate a large number of spores in a short time. A large one, about 10 centimeters in diameter, will overnight cover an area half the size of a sheet of paper of letter size with a heavy layer of spores. Attempts to revive sporophores of this fungus 16 and 19 months old were unsuccessful.

Since these fungi fruit within mills (and at least three of them (*Lenzites sepiaria*, *L. trabea*, and *Lentinus lepideus*) are known to cast spores in abundance under mill conditions) it is probable that basidiospores play an important part in the dissemination of the fungi therein.

OBSERVATIONS ON THE DISSEMINATION OF THE BASIDIOSPORES OF TRAMETES SERIALIS.

The works of Falck (14) and Buller (8) have given us some information on the dissemination of the basidiospores of hymenomycetous fungi. Falck showed how the spores were dispersed uniformly within closed glass vessels, even to some height within narrow containers. His method of determining the dissemination was by collecting spore deposits upon shelves or ledges at various locations throughout the chamber. He showed with what ease currents of air, invisible and imperceptible, caused by temperature changes could transport the basidiospores. He found that insulated fruit bodies in insulated glass chambers have a higher temperature than the surrounding atmosphere and formulated a theory that the ability to produce this higher temperature was an adaptation serving to warm the layers of air beneath the pilei for the purpose of producing convection currents to disseminate the spores. He went farther and maintained that the thickened pilei of fleshy hymenomycetes were symbiotic adaptations providing food for maggots, whose respiration produces heat. Buller (8) demonstrated basidiospore dissemination by means of his beam-of-light method. His work was more comprehensive than Falck's, and while agreeing with Falck's general conclusions as to the ease of dissemination of these spores, he could not regard it as demonstrated that the heat of the pileus was of material help in disseminating spores in the open. He maintained that the convection currents naturally present at all times out of

doors were the important agents and that any convection currents formed by the heat of the pileus would be swamped by the natural currents under most conditions. Falck in a later work (16, pp. 226–227) demonstrated how the spores of *Merulius lacrymans* are scattered throughout buildings. He found that a fruit body off in a corner in a church spread spores throughout the edifice and that spores from fruit bodies in a cellar where the temperature was a little higher than that of the rest of the house were carried by air currents to various places in the house. He caught them on glass slides under a bed on a first floor and at places on the second floor. Even a closed door did not keep them out.

The writer had no opportunity to make extended observations on the dissemination of basidiospores, but several instances came to hand which corroborated in a small way the observations and conclusions of the above-mentioned authors. Certain observations presented here have to do with the fruiting of *Trametes serialis* in the fungus pit at Madison, Wis., already referred to. Two fruit bodies of this fungus appeared toward the last of January, 1919. One of them grew at the end of the under side of a horizontal timber. On entering the pit one day it was noticed that the transverse face and a part of the upper surface of the beam were powdered white with a deposit of the spores from the fruit body below (Pl. VI, fig. 1). Several similar deposits were noted in November, 1919, when several fruit bodies appeared, most of them on the under side or on the end of another beam. Here were cases in which the spores had been swept directly upward, as if carried by a strong draft from below. But just how there could be strong drafts it is difficult to understand. The pit is sunk 4 feet in the greenhouse floor, walled with concrete, and has a dirt floor and well-fitting covers. There is very little likelihood of air currents from outside. Glass slides placed beneath the sporophore gathered no spores, but slides placed at points throughout the pit, even at the top near the covers, collected enough spores to be located under the microscope.

In mills, however, the dissemination of spores is not dependent upon such imperceptible air movements, for considerable air currents are produced by rapidly moving machinery, sprays from humidifiers, and steam pipes poorly arranged. These currents become of great importance in distributing spores which may be cast into the air by fruit bodies upon the roof planks.

In the fungus pit on two occasions the opportunity presented itself for observing to what extent insects and other animals may under certain conditions disseminate wood-destroying fungi. There is little literature bearing upon this phase of the subject. One occasionally meets with references to the connection between wood

decays and insect burrows (cf. Spaulding, 56; 57, p. 115), but little is known as to how great an extent insects are responsible for carrying the spores of these fungi and starting infections. Hubbard (25, p. 251) reports that several bark insects have been found within the veil of *Cryptoporus volvatus* and suggests that such insects may carry the spores from fruit bodies into direct contact with the inner layers of bark of uninfected trees. One beetle (*Epuraea monogama* Crotch) he found (p. 253) always coated with a thick layer of the spores. Zeller (63, p. 124) has made similar observations in connection with the same fungus. The common occurrence of fungus gnats, mites, springtails, and slugs upon hymenia has been noted by several (Buller 8, pp. 19, 20, 23, 96).

The fruit bodies of *Trametes serialis* mentioned above appeared at a time following a thaw when a considerable quantity of water seeped into the fungus pit from the earth below, making a damp chamber of the whole pit. The dampness caused an abundance of spores to be cast. The beams bearing the sporophores were so situated that they were about 1 centimeter above a piece of plank. It was so moist in this space that water had collected on the plank under the sporophore and this water was full of basidiospores. With the advent of moist conditions within the pit also came sow bugs. They infested the woody material and were particularly abundant on and around the fruit bodies, even wallowing in the water full of basidiospores. A number of these animals, with small spiders and springtails associated with them, were collected and examined for spores and, of course, were found to bear great quantities of them. All animals collected on that particular beam had spores in varying quantities on their legs, antennæ, and setæ, and many of them, particularly the sow bugs, had a large number of spores upon their backs where they had fallen directly from the sporophore. A photomicrograph (Pl. VI, fig. 2) shows the immense number of spores on the appendages of sow bugs taken from the water beneath the fruit bodies. Sow bugs caught covered with spores as just described were transferred to flasks of sterilized wood blocks and incubated. The blocks became somewhat contaminated with *Penicillium*, as might be expected, although not heavily, but a hymenomycetous growth was noted in the flasks as well. After several months the blocks were removed and found to be decayed, showing that the dissemination of wood-destroying fungi by means of arthropodous animals is possible.

The point to be made in connection with the relation of sow bugs to the possible dissemination of basidiospores within buildings is that the fruiting of these fungi and the presence of the sow bugs are often tied up with moisture conditions. Certain fungi will fruit in moist places, especially near the earth and in small inclosed places

where damp chamber conditions prevail, and the sow bugs are present in the same environment, particularly where the light is weak. Such conditions are common in and around many structures.

Springtails also are of common occurrence in the fungus pit, and are found commonly on the moist decayed wood. It is possible that other insects which inhabit buildings, such as cockroaches and spiders, may take some part in disseminating basidiospores. In mills there is the possibility that insects may assist in the dissemination of these fungi as much as they assist in ordinary cases out of doors. Insects of several unidentified species feed upon the fruit bodies of both *Lentinus lepideus* and *Trametes serialis* to such an extent that sound specimens can be obtained only within a short time after formation. Insects coming in contact with fruiting surfaces can not fail to carry away spores, because of the nature of their appendages and the stickiness of the spores, as has been demonstrated.

MYCELIUM.

PREPARATION OF CULTURES.

The cultures of the five fungi used in the physiological studies were derived from single spores of the collections already noted. The method of obtaining the single-spore cultures was essentially that of Keitt (27). The basidiospores were allowed to swell, and before the germ tubes developed several were picked out and transferred to tubes of malt agar.

MACROSCOPIC APPEARANCE OF CULTURES GROWN AT ROOM TEMPERATURE.

In cultures of *Lenzites sepiaria* on malt agar no aerial growth is seen until a day or two after the submerged mycelium has appeared, and in some cases, especially in the dark, very little aerial mycelium is in evidence at all. The aerial growth (secondary mycelium) is very scant, at first white, and breaks up almost entirely into oidia, which give the surface of the culture a more or less damp-powdery appearance. In three weeks to a month this superficial growth may become avellaneous to wood brown.³ The writer has seldom seen anything but this secondary mycelium which breaks up into oidia, but occasionally a tertiary growth will appear over the oidia-forming mycelium, forming a more matted or patchy growth. At optimum temperature (30° to 34° C.) a 10-centimeter Petri dish is covered in about eight days. On wood the superficial growth is equally scant. The surfaces of the blocks become sparingly flecked with a white, coarse powdery growth, which is found

³ All colors referred to are those in Ridgway's "Color Standards and Color Nomenclature."

to consist for the most part of oidia, with a moderate amount of strand development on the surfaces and between the blocks. This growth on wood may turn wood brown in its later stages of development. No fruit-body formation has been observed in either the agar or wood cultures.

On malt agar the first growth of *Lenzites trabea* (the secondary mycelium) is white and has the same damp-powdery appearance, due to the pressure of oidia, as *L. sepiaria*. This secondary mycelium is much more abundant than that of *L. sepiaria*, however. In ten days or more this growth is followed by the tertiary mycelium, which begins in patches and later more or less entirely overgrows the secondary mycelium. It is thick, fluffy woolly, more or less bunched, in color pale yellow-orange to light ochraceous buff, and shows no sign of the powdery appearance, because it forms no oidia. It forms large yellow-orange masses of mycelium in the upper ends of agar slants and fruits quite abundantly after a month or more. On wood the first mycelium is white, and no oidia formation has been noted. The mycelial growth is more abundant than that of *Lenzites sepiaria*, more bunched and patchy, and becomes colored as noted upon malt agar.

Trametes serialis on malt agar makes a white cottony growth, slightly patchy at times, and occasionally may be more fluffy and thick near the periphery of the culture. In later stages there is a tendency toward a snuff-brown color. In tubes the superficial mycelium forms a fluffy white mass, which grows up the walls. The upper end of the slant becomes sepia or auburn with age and occasionally develops a thick brown mass of mycelium which forms pores. On wood this fungus at first makes a thick growth over the individual blocks with some strand formation and then continues to form an abundance of white mycelium which fills the interstices between the blocks, finally covering the wood with a thick snow-white mass in three or four months. This mycelial growth may become more or less suffused with a brownish tint and may form a brown exudate in places. When the blocks are removed from the flasks after six months or more, they are covered with a thick white mass having a consistency of cream cheese. Abortive irpiciform fruit bodies, having plates instead of normal pores, are formed after six months in these block culture flasks and occasionally resupinate poroid forms develop upon the slanting sides of the flasks, connected with the mycelial mass by thick strands.

Single-spore cultures of *Fomes roseus* form a white cottony growth on malt agar, thicker and more compact than those of *Trametes serialis*, having the appearance of washed cotton flannel. They are white in color when fresh, becoming avellaneous or snuff

brown with age in patches and at the upper ends of slants. The writer's single-spore cultures from the annual form of the fungus upon coniferous hosts have only rarely developed any pink color, and then only a pale pinkish cast after 18 to 20 months of transferring. Single-spore cultures from the annual form upon *Prunus* sp. have developed colors from pink to Mars brown in patches or streaks. Tissue cultures from the annual form upon spruce have taken on only a pale-pink color, but similar cultures from the perennial form have developed a thick mat of mycelium old rose to Mars brown. The same cultures, with the exception of the single-spore cultures used in these experiments, have varied from transfer to transfer both in color and character of growth. This growth may be described as above, a thick mat, as in the tissue culture of the perennial form, or varying, thick, irregular growths, as found in other cultures. Layers of pores have been formed in the cultures derived from sporophores, but not as yet in the single-spore cultures. The culture of *Fomes roseus* used by the writer in this work is a relatively slow grower, covering a 10-centimeter Petri dish in 12 days at its optimum temperature.

On wood the slowly growing mycelium of the culture used eventually completely covers the blocks, but the growth is very thin, not at all fluffy or abundant, and the interstices between the blocks are not filled as they are by *Trametes serialis* or *Lentinus lepideus*. There is no great mass of superficial mycelium formed. The growth upon the blocks has the same washed-flannel appearance as have the agar-plate cultures, has abundant strand formation, and may become chestnut to argus brown in places in nine months or more.

Young cultures of *Lentinus lepideus* on agar are light cottony or felty, with more or less tendency to the formation of thin and thick zones of aerial mycelium. The inoculum turns snuff brown in two weeks, and the rest of the aerial growth turns buckthorn brown to cinnamon brown as it grows older, perhaps only in patches. In one month the culture may develop numerous umbonate or tubercular cushions of mycelium, which vary from white to Prout's brown, exude droplets of a dark color, and have a distinct aromatic odor. They are apparently either primordia of sporophores or abortive fruit bodies. No well-formed sporophores have developed in the writer's plate cultures. Strand formation is quite pronounced in four to six weeks. In tubes the cultures are much the same as the plate cultures. In the wood cultures in flasks the mycelial growth is abundant, covering the blocks, at first white and later becoming buckthorn brown or bister in patches, forming abortive fruit bodies in six to nine months. Clusters of long thin crystals are formed

quite abundantly throughout the flasks. The mycelium of *Lentinus lepideus* covers the individual blocks with a bunchy, uneven growth, while that of *Trametes serialis* forms a thick, even growth over the whole mass of blocks. Yet the mycelium of the former fungus binds the blocks quite solidly together, so that it takes some little effort either to remove individual blocks from the flask or to loosen the mass for emptying the flask, while the more pronounced mycelial growth of *Trametes serialis* does not have such a binding effect. The aromatic odor mentioned is much more pronounced in the flask block cultures; the other four fungi here studied do not produce such an odor.

MICROSCOPIC CHARACTERS OF THE MYCELIA ON MALT AGAR.

Lenzites sepiaria:

Secondary mycelium—

Submerged.

Colorless, avellaneous in mass; 1.5 to 4.6 μ^4 , most 2.5 to 3.2 μ ; septa fairly abundant; branching not abundant; clamps not observed; chlamydospores and oidia found occasionally on submerged mycelium, the latter chiefly in agar drop cultures.

Aerial.

Colorless; chiefly short, branched hyphæ which break up more or less completely to oidia; size same as submerged; septa fairly abundant; no clamps observed. Oidia colorless, mostly ellipsoid-oblong, occasionally ellipsoid, ovoid, globose, pyriform, or clavate, occasionally septate; terminal oidia usually clavate; 2.5 to 3 $\mu \times$ 4 to 35 μ ; helicoid hyphæ present, but not abundant.

Tertiary mycelium (aerial)—

Seldom noted in the writer's single-spore cultures. In cultures from sporophores, more abundant; long, stiff, hairlike, sparingly branched, septa not abundant, clamps at septa.

Lenzites trabea:

Secondary mycelium—

Submerged.

Colorless; 1.5 to 3 μ ; irregular; branching, clamps, and septa abundant; chlamydospores much less abundant than the oidia, thin or thick walled, terminal or intercalary, ovoid to globoid, 6 to 8 $\times$.8 to 18 μ .

Aerial.

Colorless; 1.5 to 3 μ ; branching common, usually at right angles; clamps and septa fairly abundant; oidia abundant, mostly cylindrical to ellipsoid-oblong, terminal ones ovoid to pyriform and clavate or even globoid, 2 to 8 $\times$ 6 to 24 μ , mostly about 5 $\times$ 10 μ .

Tertiary mycelium (aerial)—

Colorless, slightly yellowish in mass; long, straight, and stiff; branching and septa not abundant; clamps fairly abundant; no oidia or chlamydospores observed.

⁴ The figures in these descriptions refer to the range of measurements observed during ordinary examination.

Trametes serialis:

Secondary mycelium—

Submerged.

Colorless; 3.3 to 6.3 μ ; septa relatively few, far apart in some hyphæ, close together in others; clamps very few and small; branching more frequent than in aerial vegetative mycelium, may begin as close to growing tip as 150 μ , but usually farther back; contents of young hyphæ homogeneous, with occasional angular crystals; chlamydospores fairly common, varying more or less with age of culture, very abundant in old cultures; colorless, ellipsoid, fairly thick walled, 4.5 to 10 $\times$ 7 to 21 μ , occurring intercalarily.

Aerial.

Vegetative mycelium: Colorless; 1.5 to 3.6 μ ; septa and clamps fewer than in fruiting mycelium, but fairly abundant; branching irregular, not abundant, not necessarily at right angles, with forking common; hyphæ straight for the most part, contents homogeneous; anastomosing occasional; chlamydospores few, similar to those on submerged mycelium.

Tertiary mycelium (aerial)—

Fruiting mycelium: Colorless; 4 to 6.6 μ ; of unequal thickness, much of it with contents gone and only walls left; abundant protuberances, round or bluntly pointed; branching common, usually at clamps; septa and clamps abundant; anastomosing common; chlamydospores as above.

Fomes roseus:

Secondary mycelium—

Submerged.

Colorless; 0.8 to 3.6 μ , occasionally 4.6 μ , with much small mycelium; septa and branching not abundant; clamps not observed; branching begins near tip of young growing hyphæ; no secondary spores observed.

Aerial.

Colorless; smallest hyphæ 0.8 to 1 μ , more commonly 2 to 3.1 μ , occasionally 3.8 to 4.7 μ ; septa not abundant; branching not abundant; may or may not be at septa; clamps few; anastomosing of smaller hyphæ occasional; no secondary spores observed.

Tertiary mycelium (aerial)—

Colorless, pinkish in mass; 2 to 3 μ ; no branches or clamps; stiff, hairlike.

Lentinus lepideus:

Secondary mycelium—

Submerged.

Colorless; 3.5 to 4 μ ; septa abundant, hyphæ constricted at septa; branching may begin near tip of growing hyphæ, not necessarily at septa or clamps; clamps fairly abundant; anastomosing occasional at clamps; chlamydospores colorless, thick-walled, usually ellipsoid, occurring intercalarily or terminally on short lateral branches; 8 to 14 $\times$ 10 to 20 μ .

Aerial.

Colorless; 2 to 3 μ ; branching common, also septa; clamps few; chlamydospores colorless, 8 to 14 $\times$ 10 to 29 μ , usually ellipsoid, occasionally ovoid or ellipsoid-oblong, usually terminal, but occasionally intercalary, commonly empty, commonly showing secondary walls due to contraction of contents.

Tertiary mycelium (aerial)—

Colorless as a rule, with occasional hazel hyphæ, may be slightly colored in mass; 2.2 to 5.6 μ ; long, stiff, hairlike; chlamydospores as described in the secondary mycelium; thick walled; irregular hyphæ common.

DIFFERENTIATION OF THE CULTURES UPON AGAR.

Agar plate cultures of the five fungi under consideration in these studies are readily distinguished macroscopically. *Lenzites sepiaria* is readily distinguishable because of its scant superficial mycelium, even occasional lack of it, and the powdery appearance due to the oidia. *Lenzites trabea* can readily be distinguished as to its secondary mycelium by the presence of chlamydospores along with the oidia, inasmuch as the chlamydospores of *L. sepiaria* are very scarce and seldom found on malt agar. Its tertiary mycelium is dense, matted, and patchy and in color yellow-orange to ochraceous buff. It forms large fluffy masses at the upper ends of malt agar slants.

Of the remaining fungi here studied, *Fomes roseus* may show only a white secondary mycelium, which will be either uniform or very irregular in thickness, or there will be formed a tertiary mycelium from pale-pink tints to old rose and Mars brown in color. It is also a more slowly growing organism at its optimum temperature than *Lenzites sepiaria*, *L. trabea*, or *Trametes serialis*. *Lentinus lepideus* grows at about the same rate as *Fomes roseus*, taking 12 days at optimum temperature to cover a 10-centimeter Petri dish. *Trametes serialis* is a rapidly growing fungus, covering the dish in 7 days at optimum temperature. *Lentinus lepideus* soon takes on a brownish cast, forms umbonate abortive fruiting bodies in the Petri dishes, and usually has a distinct aromatic odor.

A conspectus of diagnostic characters of agar cultures of the five fungi is presented in key form. The characters are based on cultures at least 3 weeks old and grown at temperatures from 20° to 30° C.

I. Oidia present.

A. Growth usually white, scant and powdery, but occasionally more abundant, and shades of brown or sepia in color, especially fruit-body cultures; true chlamydospores scarce, but many spherical or pyriform oidia may be present.....*Lenzites sepiaria*.

B. Early growth (secondary mycelium) scant and powdery, but usually containing many true chlamydospores; later growth (tertiary mycelium) abundant, containing no secondary spores, pale yellow-orange to light ochraceous buff in color; abortive poroid or irpiciform fruit bodies formed.....*Lenzites trabea*.

II. No secondary spores present; tissue cultures soon becoming pink, old rose, or shades of brown; basidiospore cultures remaining white indefinitely or becoming pink with age.....*Fomes roseus*.

III. Chlamydospores present, but no oidia.

- A. Mycelium tough, brownish in old agar cultures; with abortive fruit bodies, especially in plate cultures; covers 10-cm. Petri dish in 12 days at 28° C.; aerial chlamydospores often showing contraction of the protoplasm and formation of thick secondary walls; usually having a strong aromatic odor.....*Lentinus lepideus*.
- B. Mycelium white; no abortive fruit bodies; covers 10-cm. Petri dish in seven days at 28° C.; chlamydospores more abundant in submerged mycelium.....*Trametes serialis*.

EFFECT OF TEMPERATURE ON THE GROWTH OF THE MYCELIUM.

The tests on the effect of temperature upon the growth of the mycelium were made on malt agar in 10-centimeter Petri dishes. The

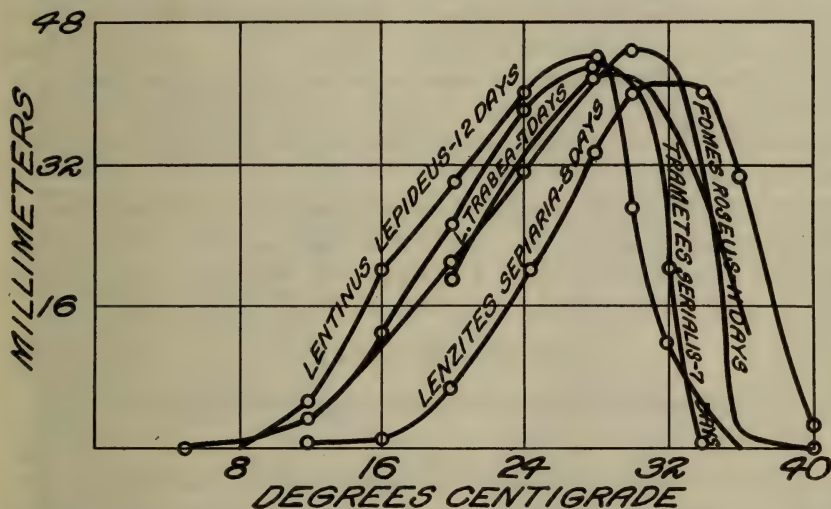


FIG. 2.—Effect of temperature upon the growth of the mycelium upon malt agar (shown in millimeters of radial growth from the inoculum).

inoculum consisted of a block of agar 8 to 10 millimeters square, with its mycelium, cut from the young growth of a previously prepared Petri dish culture. This transfer was deposited upon the surface of the agar in the center of the dish. Growth was measured in millimeters radially from the edge of the inoculum. The results of the tests upon the five fungi are given in figure 2 and in Plate VII. For *Lenzites sepiaria* the optimum lies at 30° to 34° C. (85° to 93° F.). At 3° and 8° C. (37° and 46° F.), there was no noticeable growth in 8 days, and after a month there was no growth at 3° C. and only a millimeter or two at 8° C. At 40° C. (104° F.) results varied. Occasionally there was no noticeable growth until after 18 days, when it varied from 1 to 3 millimeters; at other times 1 to 5 millimeters was evident in 8 days. No growth took place at 44° C. (111° F.). Falck (15, pp. 127–129) obtained somewhat different results for this fungus.

He found the optimum to be 35° C. (95° F.), the minimum 5° C. (39° F.), and the maximum point 44° C. (111° F.).

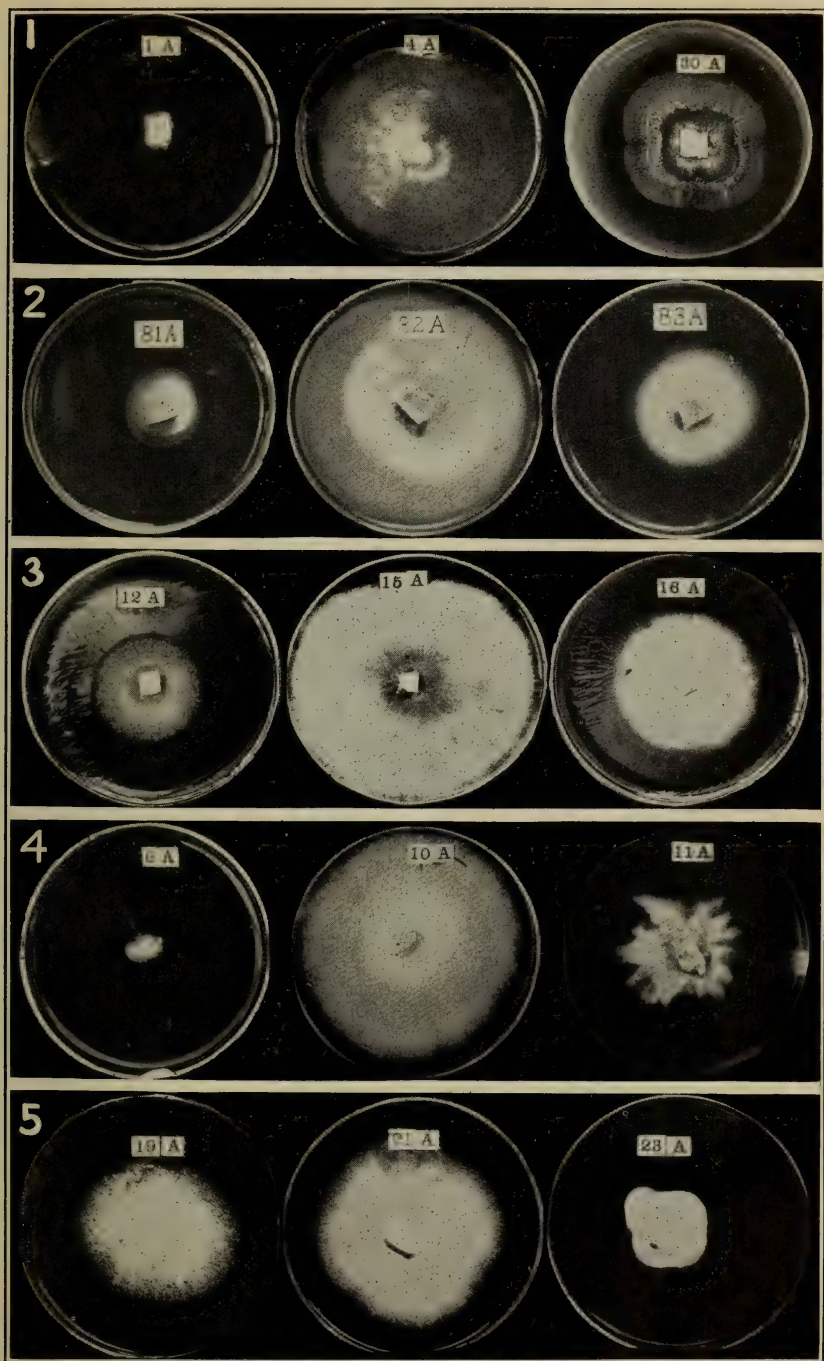
Lenzites trabea makes a moderately rapid growth, covering the dish in seven or eight days. It grows fastest at 28° C., although nearly as rapidly at 30° C. It grows only very slightly at 40° C. (104° F.).

Trametes serialis grows at about the same rate as *Lenzites sepiaria*, covering the dish in 7 days. The optimum for *T. serialis* is at 28° C. (82° F.). No growth occurred at 34° C. (93° F.), and at 3° C. (37° F.) none was noticed until after 39 days, when it was seen to be alive and barely growing. *Fomes roseus* is a more slowly growing organism, taking 11 days at the optimum temperature (30° C.) to cover the 10-cm. Petri dish used. At 3° C. there were signs of growth in 12 days, but very little at 36° C. (97° F.) and none at 40° C. (104° F.). Upon microscopic examination it was seen that at 40° C. hyphæ had started to grow, but had died. *Lentinus lepideus* also grows at a moderate rate; in most of the tests the dish was not quite covered in 12 days. Its optimum was found to be 28° C. (82° F.). Its range of growth was narrower than that of the other three fungi. No growth was noted at 8° C. (46° F.) in 12 days, and at 36° C. (97° F.) there was less than 1 mm. in the same period. No growth was visible at 40° C. (104° F.).

SECONDARY SPORES.

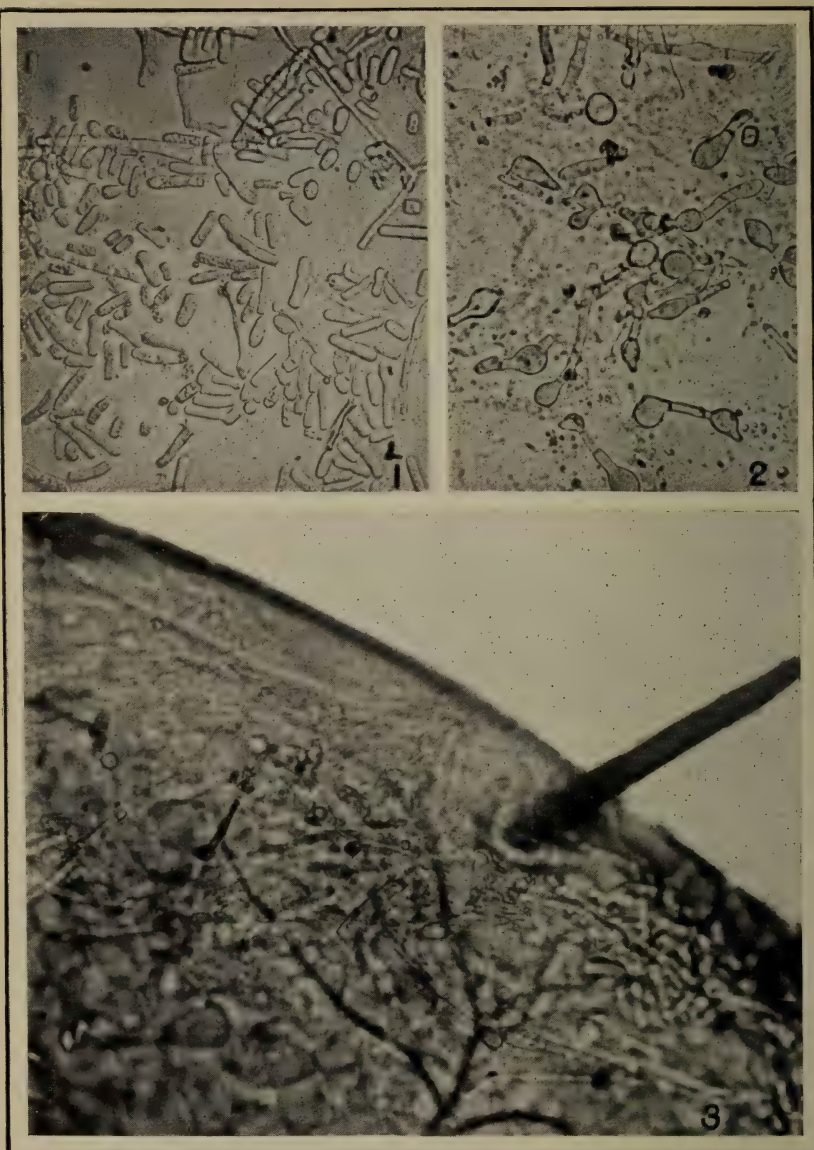
INTRAMURAL DISSEMINATION OF FUNGI CAUSING DECAY.

One of the most interesting problems in connection with the decay of building timbers is that of the intramural dissemination of the causal organisms. Abundant proof is at hand to attest the activity of the mycelium in spreading decay throughout a building by direct growth from one timber to another. Falck (16, pp. 245-247) has shown how the mycelium of the dry-rot fungus (*Merulius lacrymans*) can grow through structures and even for some feet over brick and stone masonry from one piece of timber to another. Wehmer (61) has shown the same for cultures of *Coniophora cerebella*. The dissemination of *M. lacrymans* by means of rhizomorphs is also well known (cf. Falck and others). The dissemination by means of basidiosporic fructification has already been mentioned. While conditions in textile and paper mills may occasionally favor the formation of fruit bodies, of certain species at least, conditions also may prevail which will likewise prevent the formation of such fruit bodies. It has been shown that *Trametes serialis* can fruit and cast spores in the dark. On the other hand, *Lenzites sepiaria* can not form normal fruit bodies in the absence of light (see Falck, 15, for reference and discussion), and the same is true of *Lentinus lepideus*.



EFFECT OF TEMPERATURE UPON THE GROWTH OF THE MYCELIUM.

FIG. 1.—Growth of *Lenzites sepiaria* for 8 days: 1A, at 18° C.; 4A, at 32° C.; 30A, at 36° C. FIG. 2.—Growth of *Lenzites trabea* for 7 days: 81A, at 16° C.; 82A, at 28° C.; 83A, at 36° C. FIG. 3.—Growth of *Trametes serialis* for 8 days: 12A, 12° C.; 15A, at 28° C.; 16A, at 32° C. FIG. 4.—Growth of *Fomes roseus* for 11 days: 6A, at 12° C.; 10A, at 30° C.; 11A, at 34° C. FIG. 5.—Growth of *Lentinus lepideus* for 12 days: 19A, at 24° C.; 21A, at 28° C.; 23A, at 32° C.



FUNGI STUDIES OF IMPORTANCE IN THE DECAY OF BUILDING TIMBERS.

(X 523.)

FIG. 1.—Oidia of *Lenzites sepiaria* from malt-agar culture. FIG. 2.—Stages in formation of chlamydospores of *Trametes serialis* on secondary mycelium in malt agar, with a few thin-walled chlamydospores. FIG. 3.—Oidia and mycelium of *Lenzites sepiaria* upon fibia of cockroach allowed to roam over wood block culture over night.

(Buller, 6, p. 428; 7, p. 6; and Jaczewski, 26, p. 407). Under these circumstances the question naturally arises whether or not secondary spores might be produced by some of these organisms and thus account for the rapidity with which decay spreads in certain types of buildings. In certain places in mills, as basements and between floors, for example, light may be insufficient for fruit-body formation, yet this lack of light and the abundance of moisture would be highly favorable for the growth of superficial mycelium, and hence, perhaps, for the production of secondary spores. With these possibilities in mind, considerable attention was paid to the observation and study of the secondary spores formed by the five organisms in question.

REVIEW OF THE LITERATURE OF SECONDARY SPORE FORMATION.

GENERAL SUMMARY.

The subject matter relative to secondary spores has been well summarized by Lyman (31). His conclusions (p. 202) were: That a majority of the hymenomycetes have no secondary spores; that oidia are common among the Polyporaceæ and Agaricaceæ and are confined to these two families; that chlamydospores occasionally occur in connection with the basidial fructification and are quite widely distributed on the mycelium of all families; and that conidia and other highly specialized methods of reproductions (bulbils, etc.) are rare and occur more frequently in the Thelephoraceæ than in the higher families. Since Lyman's paper, only scattering references to secondary spores have appeared. Of these only a few are of interest here. Marryat (32) found chlamydospores of *Pleurotus subpalmatus* in the vessels of wood-block cultures. Rumbold (49) not only reported secondary spores for the first time in a few species of wood-destroying fungi, but studied their formation, germination, and subsequent development. Falck produced two comprehensive volumes, one in 1909 on the decay produced by species of *Lenzites* (15) and the other in 1912 on the decays caused by species of *Merulius* (16). In these he takes up in a thorough way the occurrence, the methods and conditions of formation, and the germination under various conditions of the oidia in the species considered. In the later work (16, p. 132-133) he makes some general remarks upon these oidia. He considers them of two kinds—a transition, or tiding over, form (*Übergangsfruchtform*), as found in *Merulius*, and a true secondary form (*Nebenfruchtform*), as found in *Coniophora*. The former he says are not formed under normal conditions (*natürlichen Verhältnissen*) but only when conditions become unfavorable for growth of the fungus. Their viability is reduced and they are capable of being disseminated only to a slight degree. The latter are found under

normal conditions of growth, and their formation is independent of environmental conditions. They germinate immediately and normally, are formed in loose dustlike masses, and are easily removed. The former he considers a facultative transition form and the latter a true propagative form.

Hotson in two papers (22 and 23) extended and summarized our knowledge of bulbils and similar propagative forms, and added the finding of bulbils in a few basidiomycetes. Learn (28), in his cultures of *Pleurotus ostreatus*, noted the formation of new mycelial growths at the base of wood-block cultures below blocks bearing oidia. This suggested the shedding of these oidia from above. Weir (62) noted a *Ptychogaster* form in connection with *Trametes suaveolens* growing naturally, and he remarks that in the damp woods of Idaho there are many abnormal polyporoid forms, some of them conidial. In *Fomes officinalis*, Faull (18) found chlamydospores not only in cultures but also in the crust of the sporophores. The writer has found the chlamydospores of this fungus on rotting wood in nature (55). Hiley (20) reviewed the status of the conidia of *Fomes annosus*.

REFERENCES TO THE OCCURRENCE OF SECONDARY SPORES IN NATURE.

The references to secondary spores occurring in nature are quite numerous. Perhaps the least understood of the fungi producing secondary spores are the *Ptychogasters*, which are considered abnormal conidial or chlamydospore fructifications of the polypores. Observations on the *Ptychogasters* occur chiefly in the older literature, and reference may be had to Boudier (3 and 4), De Seynes (50, 51, 52, 53, 54), Richon (48), Ludwig (30), Patouillard (42 and 43), Brefeld (5), and Weir (62). Then there are the spores reported as conidia, called "wet-weather spores" by Lyman (31, p. 135), who said that until these spores had been more thoroughly investigated their nature must be regarded "as uncertain and their occasional production as of doubtful importance to the fungus." (Cf. Patouillard, 41, 44, 46; Eichelbaum, 11; and Masee, 33.) Of the references to secondary spores in nature the status of which is more certain, we might mention the following: Chlamydospores on the hairs of the stipe of *Pleurotus ostreatus* (Patouillard, 39) and in the hymenium (Matruchot, 34); chlamydospores in groups or singly in *Trametes rubescens* (*Daedalea confragosa*) (Patouillard, 40); chlamydospores in fruit bodies of *Polyporus sulfureus* (De Seynes, 50, 51); conidia (chlamydospores according to Lyman, 31, p. 136) in the hymenium of *Hydnum coralloides* (De Seynes, 53); terminal chlamydospores in *Fistulina hepatica* (De Seynes, 50); chlamydospores on and in the pileus of *Nyctalis asterophora* and *N. parasitica* and conidia of *Fomes*

annosus found by Olsen (Brefeld 5, p. 177); chlamydospores between the margin and the poriferous zone in *Polyporus bambusinus* (Patouillard, 45); conidia (chlamydospores according to Lyman) in *Stereum disciforme* and all over the hymenium of *Aleurodiscus oakesii* and *A. amorphus* (Patouillard, 46); conidia on racemose organs in the hymenium before formation of basidiospores in species of *Aleurodiscus* (Burt, 9, p. 198); viable chlamydospores on branches of the stipe of *Collybia racemosa* (Stefan, 59); helicoid conidia on hairs arising from the young veil and from the margin of the developing pileus of *Lentodinium squamulosum* (*Lentinus tigrinus* Fr.) (Lyman, 31; p. 186) and on the mycelium overgrowing the gills of the same fungus (Murrill, 38, p. 296). Further, Cool (10) found oidia coming from the pileus during basidiospore casting of *Collybia velutipes* (p. 9) and chlamydospores along with the basidiospores of *Sphaerobolus stellatus* (p. 21). She also reports that she found a great many more oidia than basidiospores in the hymenial layer of *Collybia velutipes* and wart-shaped heaps of oidia on the dried fruit bodies of this fungus. Long and Harsch (29) report the chlamydospores of *Lentinus lepideus*. We have already mentioned Weir (62) and the observation of Faull (18) and the writer (55) on the chlamydospores of *Fomes officinalis*.

REFERENCES TO THE IMPORTANCE OF SECONDARY SPORES IN THE DISSEMINATION OF FUNGI.

There are a few references to the importance of secondary spores in the dissemination of fungi. Eidam (12, p. 245) concluded that there was no natural secondary reproduction in *Cyathus striatus* and that the oidia were an abnormal appearance, although they might tide over unfavorable conditions. In speaking of the failure of Hartig's isolation trench in checking the spread of *Fomes annosus*, Brefeld (5, pp. 153 and 179-185) suggested as the reason that conidia were formed by this fungus that they infected the cut roots and thus produced more disease than normally occurred. Brefeld never found conidia growing naturally, although he reports such a finding by Olsen (5, p. 177), but he obtained them in the laboratory on mycelium collected in the woods (5, p. 153). Hiley, in reviewing the status of the conidia of this fungus in relation to decay of the larch, reports (20) the production of conidia in wood cultures and upon sterilized soil. He believes it probable that the mycelium of *Fomes annosus* "may grow on forest soil and bear conidia" (p. 115) and that one of the means of infection of the host is by these conidia (pp. 115, 121, 123). Tubeuf (60, p. 103) had nothing concrete to offer on the propagation of *Merulius* by secondary spore forms, but emphasized the theoretical importance of such. He pointed out that

the basidiospores of the dry-rot fungus are difficult to germinate and may have low germinability in nature. He further states that the chlamydospores (asserted to be oidia by Falck) if found outside artificial cultures would probably contribute to the spread of the fungus. Falck (16, p. 132), on the other hand, maintained that the oidia of *Merulius* were not true propagation organs. The same writer in 1902 (13, p. 319) remarked that insects must spread the oidia of *Hypholoma* and *Pholiota*, which are formed in abundance on firm substrates. He believed that the formation of oidia on blocks infected with *Collybia velutipes* placed in moist moss illustrated the importance of these spores in nature. These oidia were formed in colonies in the air, undoubtedly for insect dissemination, he avers, but he doubts whether they could be detached by the wind. Falck (15, p. 144) also maintained that the tertiary oidia of *Lenzites sepiaria* "doubtless play an important part as organs of propagation, inasmuch as the spores might easily be carried away by animals in creases of their bodies, etc. A somewhat rough shaking loosens single end-spores from one another, and these can easily be collected on slides held beneath."

Münch (37, p. 577), however, believes that oidia do not possess in nature the great significance for the spread of the fungus which Falck claimed for them. He observes that the conditions of oidia formation are not clear, that their formation in nature is not possible in cases that have come to his attention, because of the inability of the fungus to get to the air, and that direct observations of oidia in nature are lacking. He asserts that this form of reproduction is merely a makeshift at best and not a normal reproductive form. Faull (18, p. 201), as mentioned above, found chlamydospores in the crust of sporophores of *Fomes officinalis* and expressed the belief that they are a means of reproducing the fungus, although the viability of these chlamydospores appearing naturally was not tested. The finding of chlamydospores of this fungus in nature by the writer (55) has suggested their importance in the spread of the fungus.

OCCURRENCE OF SECONDARY SPORES IN CULTURES OF THE FUNGI STUDIED.

Of the five fungi used by the writer in these studies, secondary spores have been found in four. Oidia have been previously reported in cultures of *Lenzites sepiaria* by Rumbold (49) and Falck (15) and chlamydospores also by Falck. Long and Harsch (29) reported the occurrence of chlamydospores in cultures of *Lentinus lepideus*. As far as the writer knows, the chlamydospores formed by *Trametes serialis* have not been reported, although Mez (35, p. 116) mentioned a brown corky *Ptychogaster* form of this species

with deep pores. Brefeld (5, p. 106) reported in *Trametes serialis* aerial oidia which would germinate and made the observation that their formation occurred only on young mycelium, never on old. The writer's cultures have developed no oidia. The oidia and chlamydospores in *Lenzites trabea* have not been reported. No secondary form has been noted in *Fomes roseus*. Chlamydospores have been seen in cultures of *Lenzites sepiaria*, but have been scarce. They could not have appeared abundantly in Falck's cultures, for he little more than mentions them. All his references to secondary spore production by this fungus are to the oidia, and he describes no physiological tests upon the chlamydospores.

Oidia have appeared to a limited extent in the submerged mycelium of *Lenzites sepiaria*, chiefly in the hanging agar drop cultures (Pl. III, figs. 3 and 10), while the aerial oidia have been quite abundant with some variations (Pl. III, figs. 4-7; and Pl. VIII, fig. 1). Oidia have been quite abundant also in wood cultures. What little aerial mycelium forms on either wood or agar breaks up almost entirely to oidia. The occurrence and method of formation has been described sufficiently by Falck (15, pp. 139-140). He describes primary, secondary, and tertiary oidia according as they are formed on primary, secondary, or tertiary mycelium. The secondary oidia are never formed on the natural substrate of the fungus, according to him, but abundantly on agar, while the whole superficial growth of tertiary mycelium on agar or wood forms oidia in moist air. Chlamydospores and chlamydosporelike bodies (Pl. III, figs. 12 and 13) are found in small numbers upon the submerged mycelium. The secondary mycelium of *Lenzites trabea* develops oidia in abundance (Pl. IV, fig. 2) and chlamydospores in fair numbers (Pl. IV, figs. 3 and 4). The oidia are formed on the superficial mycelium and the chlamydospores on the submerged so far as can be determined. Some of the latter spores are thin walled and appear much like rounded oidia. Many of the chlamydospores show the contraction of the protoplasm and the abandoned cross walls (Pl. IV, fig. 4), as in the chlamydospores of *Trametes serialis* and *Lentinus lepideus*.

The chlamydospores of *Trametes serialis* (Pl. IV, figs. 6, 7, 8; and Pl. VIII, fig. 2) have appeared regularly in the writer's cultures and fairly abundantly. They are found for the most part on the submerged mycelium, although sparingly in the aerial fruiting mycelium at the upper end of older agar slant cultures, where abortive fruit bodies are formed. The method of development is that described by Lyman for other basidiomycetes (31, p. 150, pls. 19, 21, and 22) and illustrated in Plate IV, figure 6, and Plate VIII, figure 2.

The chlamydospores of *Lentinus lepideus* (Pl. V, figs. 4 and 5) have never been found abundantly. They occur in a living condition

on the submerged mycelium after about 10 days, but are empty and dead in 2 months.

The secondary spores of the four species considered here are formed on all the nutrient media tried, although in varying quantities, but *Lenzites sepiaria* is the only species so far known to form them on wood. Temperature has no appreciable effect on the formation of these spores on malt agar. Early in the work it seemed as if light favored the formation of oidia by *Lenzites sepiaria* and that darkness prevented it, but a variety of tests, variously checked, failed to give absolutely consistent results. Yet it was found that cultures started in the light nearly always formed oidia, while those in the dark seldom did.

GERMINATION STUDIES OF THE SECONDARY SPORES.

The oidia of *Lenzites sepiaria* germinate readily and to practically 100 per cent on agar. The cylindrical oidia as a rule simply lengthen out at either end or both ends with no swelling, so that no sign of the original oidium is left (Pl. III, fig. 11). Germination may begin, however, with a swelling of the oidium, at one end or in the middle, and the germ tube may then arise from either the swollen or unswollen ends (Pl. III, fig. 9). The club-shaped oidia which are found occasionally may send out one or more tubes from either the swollen or unswollen ends. In water the tubes are attenuated. The chlamydospores of *Lenzites sepiaria* germinate normally (Pl. III, fig. 10). The oidia and chlamydospores of *Lenzites trabea* germinate in a manner similar to those of *L. sepiaria*. The chlamydospores of *Trametes serialis* (Pl. IV, fig. 9), and *Lentinus lepideus* send out tubes from either end of the ellipsoid spores, although usually from only one end.

Germination tests were carried out upon the oidia of *Lenzites sepiaria* and *Lenzites trabea* and the chlamydospores of *Trametes serialis*. The chlamydospores of *L. sepiaria* and *L. trabea* were not readily obtainable in sufficient quantities and were hard to separate from the oidia. The chlamydospores of *Lentinus lepideus* could not be obtained in a condition which would allow of their manipulation. The chlamydospores of all four fungi occur chiefly, if not entirely, on the submerged mycelium in the agar. Those of *Trametes serialis* could be obtained in sufficient numbers by scraping the submerged mycelium, with as little agar as possible, from the surface of the culture, then macerating this material between two thick glass slides which had been previously flamed and finally removing this macerated mixture to sterile water blanks. The chlamydospores were separated from the mycelium by this process and the mycelium sufficiently injured so that it did not interfere with germination

tests. This method was not entirely satisfactory, but was the best that could be used in view of the lack of chlamydospores in quantity on the aerial mycelium. This method would not produce results with the chlamydospores of *Lentinus lepideus*, however, because they could not be separated from the mycelium, which appeared to be rather tough. The spores were not abundant in the first place, and germination tests on the few obtained were unsatisfactory, because the mycelium in the macerated mass overgrew the germinating chlamydospores.

All of the secondary spores germinate readily on various agars or in tap water. In distilled water numerous tests have shown that the oidia germinate sparingly (usually less than 1 per cent and produce only a small amount of attenuated mycelium. The chlamydospores could not fairly be tested in distilled water, on account of the difficulty in obtaining the spores free from mycelium, agar, etc., as explained above. On red spruce the secondary spores germinate normally as to time and manner, although forming attenuated mycelium.

TEMPERATURE.

The curves shown in figure 3 represent the effect of temperature upon the germination of oidia of *Lenzites sepiaria* and *L. trabea* and the chlamydospores of *Trametes serialis*. It will be noted that most of the oidia of both species germinated even at the extreme temperatures. At 5° C. (22° F.) in 5 days only 35 per cent of the oidia of *L. sepiaria* had germinated, 75 per cent in 11 days, and 80 per cent in 14 days. At 44° C. (111° F.) the oidia of both *L. sepiaria* and *L. trabea* germinated to practically 100 per cent in 20 hours. The oidia of *L. sepiaria* germinated most rapidly at 36° C. (97° F.) and that of *L. trabea* at 32° C. (89° F.).

About 75 per cent of the chlamydospores of *Trametes serialis* germinated between 20° and 32° C. (68° and 89° F.). In three weeks 35 per cent germinated at 50° C., but none germinated at 36° in repeated tests. The rate of development was optimum around 28° and 32° C. (82° and 89° F.).

A comparison of the cardinal temperatures for rate of germination of the basidiospores and secondary spores with growth of the mycelium of the five fungi studied shows that they correspond quite closely. The optimum for basidiospores extends over a little wider range of temperature than for the secondary spores or mycelium. The maximum temperature for the germination of the basidiospores is somewhat higher, by a few degrees, than for the growth of the mycelium of all five fungi. The oidia of *Lenzites sepiaria* and *L.*

trabea showed little or no retarding effect in percentage of germination at 44° C.

A single test upon the effect of cold on the oidia of *Lenzites sepiaria* and chlamydospores of *Trametes serialis* was made. Slides

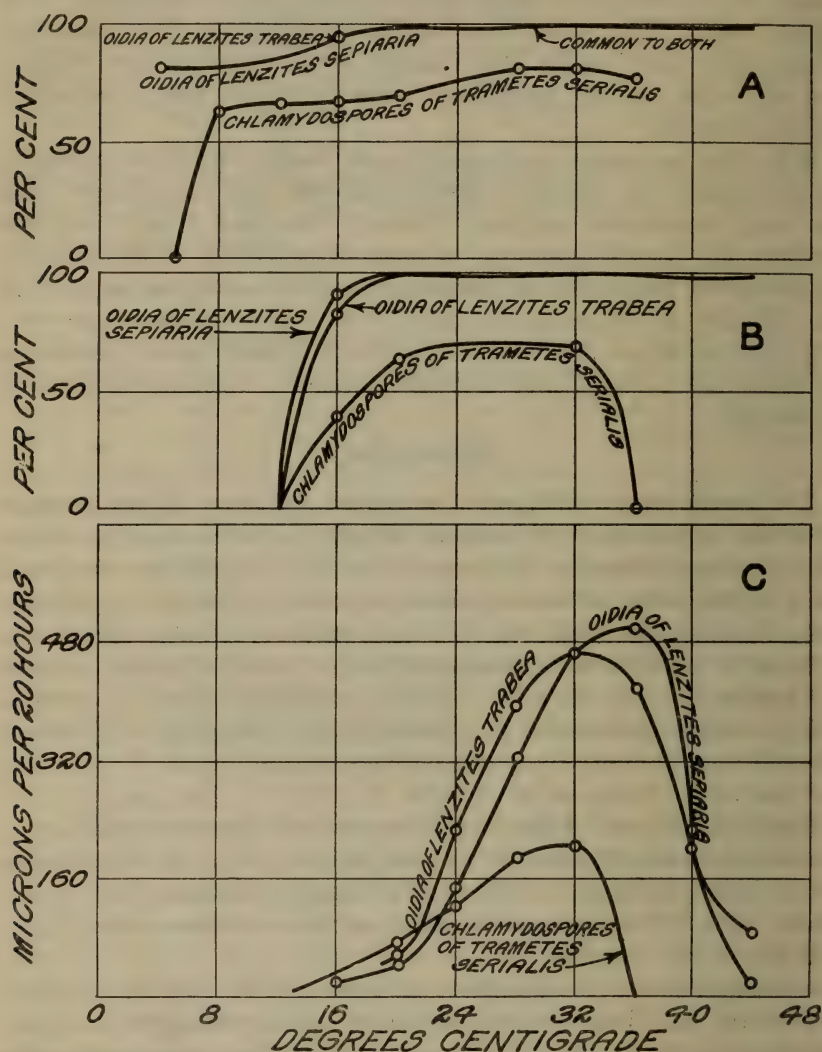


FIG. 3.—Effect of temperature upon the germination of the oidia of *Lenzites sepiaria* and *L. trabea* and of the chlamydospores of *Trametes serialis*. A, Effect of temperature upon the percentage of germination, showing the maximum percentage obtained, regardless of the time element; B, percentage of germination in 20 hours; C, rate of growth of the thalli in 20 hours (shown in microns).

were left out of doors over night when the temperature varied from -19° C. to -23° C. (-3° to -10° F.). The next morning germination tests were made, and it was found that the oidia had not been

affected, practically 100 per cent germination resulting, while the chlamydospores did not germinate at all.

LIGHT.

The diffused light from an east window during the winter apparently had little effect on the germination of the secondary spores. The oidia of *Lenzites sepiaria* and *L. trabea* germinated almost perfectly in diffused light or in the dark, although the development was somewhat more rapid in the dark. The same is true of chlamydospores of *Trametes serialis*, except that the percentage was between 50 and 60 rather than around 100.

In the month of May, 10 hours of direct sunlight acting upon the secondary spores upon agar not only inhibited germination during that period but prevented subsequent germination altogether. Experiments upon the killing effect of direct sunlight upon these spores when resting could not be carried out, inasmuch as it was impossible to separate the effects of drying from the effects of sunlight, because, as will be shown, drying materially reduces the percentage of germination.

DRYING.

There have been a few reports of the resistance of secondary spores to drying. De Seynes (50) found that the conidia of *Fistulina hepatica* germinated after four years. Brefeld (5, p. 153) said that the conidia of *Fomes annosus* retained their viability for one year and a few germinated after two years of drying. He also stated (5, p. 27) that the oidia of *Phlebia merismoides* resisted drying for a month and some germinated after six months. According to Falck (15, p. 146) the aerial oidia of *Lenzites sepiaria* are resistant to drying. Oidia subjected to drying in the presence of calcium chlorid germinated after one year, and they were not killed after an exposure of several hours to 60° C. (p. 147). On the other hand, Lyman (31, p. 149) concluded that in general the retention of viability by oidia is of short duration.

The writer's results with the oidia of *Lenzites sepiaria* and *L. trabea* agree with Lyman's conclusions. Agar cultures with an abundance of oidia and oidia on glass slides were dried for varying periods. After one day of drying the percentage of germination was much reduced, and usually to less than 1 per cent. In some cases, however, a very small percentage of oidia would germinate after a few months at room temperature, perhaps because of protection of certain oidia by large masses of others. It was thought that if any resistance to drying should be manifested it would be on the natural substrate for the fungus, but the results were the same as on agar.

The chlamydospores of *Trametes serialis* proved no more resistant. It is possible, however, that the conditions under which they were formed (in a moist medium) and their previous wetting in obtaining them may render them more sensitive to drying.

ALTERNATE WETTING AND DRYING.

The oidia of *Lenzites sepiaria* and *L. trabea* do not survive alternate wetting and drying. Oidia were removed in quantities from an agar plate culture to glass slides. Two slides were retained as checks and the oidia on two others were wet with sterile distilled water and immediately put away until dry. One slide was allowed to dry under room conditions, while the other was dried in the presence of calcium chlorid. Germination tests were then made. After 16 hours the controls showed practically perfect germination, while of the wet and dried oidia three Van Tieghem cells showed less than 1 per cent and one 5 per cent germination. Repetitions of the test gave similar results.

EXPERIMENTS UPON THE DISSEMINATION OF THE OIDIA OF LENZITES SEPIARIA.

Flask cultures of *Lenzites sepiaria* and *L. trabea* obtain a much better start than cultures of the other fungi, because of the oidia. The water in the tube containing the bean-pod cultures used as inoculum becomes a suspension of oidia, and these are distributed all over the flask to start centers of growth, whereas cultures of fungi possessing no oidia can only be spread from the inoculum and consume about one month in covering all the blocks in the flask. In the light of these facts a few experiments were carried out with a view to ascertaining by what means and how easily the oidia of this fungus might aid in dissemination. It is realized that any points made here are contingent for their importance upon the question as to whether or not the oidia occur naturally. Inasmuch as Falck (13, p. 319) doubted whether wind would be of any importance in disseminating oidia, the writer set out to determine how easily the oidia might be removed from plate cultures. A new transfer was inverted over a sterile agar plate, sealed with gummed paper, and set away in the incubator. In the first test with *L. sepiaria*, an abundance of oidia were found upon the sterile agar plate after a week. Repetitions gave inconsistent results, but it was shown that small numbers of oidia may be released during their formation. Shaking a plate culture over a sterile agar plate yielded results similar to those reported by Falck (15, p. 144). Oidia were dislodged in some cases, but not in all. The same test was tried with *Collybia velutipes*, and pure cultures were obtained from oidia shaken off.

Attempts were next made to dislodge oidia from agar-plate cultures by air currents from an electric blower delivering 1.4 cubic feet per minute. The apparatus was so set up that at least a part of the oidia removed would lodge on sterile agar plates. From cultures with a very heavy development of oidia, a very few were dislodged, as determined by microscopic examination of the surface of the sterile agar plates and subsequent growth. An electric fan making a much stronger current of air removed larger, though not considerable, numbers of oidia. Oidia on wood blocks from cultures were not removed any more readily, inasmuch as they are formed only in moist atmospheres and are themselves moist and sticky. The same procedure was tried with other species showing secondary spores in culture. Individual oidia or small clusters were likewise dislodged from agar cultures of *Collybia velutipes*. The stronger current of air removed a few of the chlamydospores of *Fomes officinalis*, but oidia could not be removed from cultures of *Coniophora cerebella* or *Merulius lacrymans* or chlamydospores from cultures of *Trametes robiniofila* or *Fomes igniarius*. It is thus seen that secondary spores of most of the species mentioned do not appear to be adapted to dissemination by wind.

Oidia are readily removed by contact. Prints can be made upon glass slides or cover slips by simply allowing the glass to touch the surface of a culture. More sticky substances like agar retain more oidia than glass. The obvious application of these facts is insect dissemination, for insects with sticky feet and hairy or bristly appendages should be able to remove and carry away large numbers of the moist oidia. A cockroach caught in the laboratory was placed upon agar cultures of *Lenzites sepiaria* for a few minutes. Examination of the roach's appendages under the microscope disclosed large clumps of the oidia stuck to the tarsi. Another roach placed upon an agar culture was transferred to a sterile agar plate, allowed to remain a few seconds, and then the plate was incubated. In three days the plate showed a winding growth of *Lenzites sepiaria* and contaminations, chiefly *Penicillium*, presumably where the roach had walked over the agar during his captivity. A cockroach was then placed in a flask containing a wood-block culture of *Lenzites sepiaria* and examined after a few minutes. A few oidia were found upon the pads of the tarsi and on the bristles of the legs and antennæ (Pl. VIII, fig. 3).

Water will dislodge large quantities of oidia from agar or wood cultures. Sterile water dropped from a pipette upon the inoculum of a new transfer will carry or splash large numbers of oidia on the surrounding sterile agar.

From the above results it is concluded that oidia occurring either on wood or agar are moist, sticky spores, not adapted to air dissemi-

nation, but excellently adapted to dissemination by insects or dripping water. The practical application of these facts is obvious. If secondary spores occur outside of artificial cultures, there is no place more suitable for their formation than in the structures of wet occupancy referred to. In these structures, where conditions are moist, there would be insects or animals, such as sow bugs and cockroaches, and there is commonly dripping water, precipitation water upon cool masonry, around cold-water pipes, etc.

OCCURRENCE IN BUILDINGS OF THE SECONDARY SPORES OF THE FUNGI STUDIED.

The step following the demonstration that oidia can disseminate fungi, such as *Lenzites sepiaria* and *L. trabea*, is to prove that such oidia occur naturally in buildings. The outstanding fact is that many European writers have suggested the importance of the secondary spores in the economy of the fungus, if found naturally, and that no one has yet reported such occurrences. The writer has little information on the subject. The only secondary spores found in mills are the chlamydospores on the mycelium overgrowing the gills of fruit bodies of *Lentinus lepideus* (Pl. V, fig. 6). These are formed quite abundantly, but thus far nothing is known of their ability to disseminate the fungus. The spores which the writer found were on old fruit bodies, and tests as to their ability to germinate failed. There is, of course, the possibility that freshly formed chlamydospores may germinate, and, if so, they would disseminate the fungus much as do the basidiospores which are overgrown and imprisoned by the chlamydosporic mycelium. This means of dissemination would appear to be not so efficient a method as by the basidiospores which they replace, because the basidiospores should be lighter and hence capable of wider dissemination.

It is known that certain fungi do form superficial mycelium within the structures referred to in these studies as well as out of doors. Falck (15, p. 154) relates that the fruit-body-forming mycelium (*fruktifikative Oberflächenmycel*) of *Lenzites sepiaria* is found on moist places on beams, and he states (15, p. 143) that it is capable of producing oidia, although he has not reported the finding of these oidia in buildings. The writer has examined some superficial mycelium of *Lenzites sepiaria* and *L. trabea* upon planks secured from mill roofs, but the presence of oidia or chlamydospores as yet has not been definitely established.

SUMMARY.

In textile and paper mills prevailing conditions of humidity and temperature provide a favorable environment for the development of wood-decaying fungi. Under such conditions poorer grades of

timber, such as inferior southern pine, spruce, and hemlock, which have been used in mill construction in recent years, are readily attacked and destroyed. Hence, the losses through decay by a certain group of fungi are large. Because of the practical importance under mill conditions of *Lenzites sepiaria*, *L. trabea*, *Trametes serialis*, *Fomes roseus*, and *Lentinus lepideus*, studies upon the physiological relations of the basidiospores, mycelium, and secondary spores were undertaken, particular attention being paid to those factors influencing intramural dissemination.

All five of these fungi have been found fruiting more or less commonly upon mill roofs or in basements. *Lenzites sepiaria* and *L. trabea* do more damage to coniferous roof timbers than has heretofore been reported.

The basidiospores of the five fungi will germinate upon various agars, or wood, in tap water, and irregularly in distilled water.

At 40° C. the basidiospores of *Lenzites sepiaria* will germinate in large percentages, while those of *L. trabea* and *Fomes roseus* give small percentages. The spores of the other two fungi will not germinate at this temperature. The optimum temperatures for rapidity of germination are: *Lenzites sepiaria*, 32° to 35° C. (89° to 97° F.); *L. trabea*, 28° to 32° C. (82° to 89° F.); *Trametes serialis*, 30° to 32° C. (86° to 89° F.); *Fomes roseus*, 28° to 32° C.; *Lentinus lepideus*, 28° C. Large percentages of the spores will germinate at the lower temperatures within the range of growth for each fungus if sufficient time is allowed. The percentage of germination is the criterion which best shows the effect of temperature upon the viability of the spores.

Diffused light did not affect the germination of the spores. The basidiospores of these fungi would not germinate in direct sunlight in May, and after two days of exposure few or no spores would germinate when put in the dark. Two days of direct sunlight in May acting upon dry spores usually killed all but a very small percentage, if not all of them. The germ tubes showed no phototropic responses.

In drying tests, basidiospores of *Trametes serialis* and *Lentinus lepideus* (aged 10 days and 7 months, respectively) were killed in about 10 weeks' exposure at 28° and 32° C. (82° and 89° F.) and in about a month at 36° C. (97° F.). With fresh spores at 40° C. (104° F.), *Lenzites sepiaria* survived two months and *Trametes serialis* six weeks in an unfinished test. Spores of *Fomes roseus* five months old were killed in one week at the same temperature.

Alternate wetting and drying is destructive to the spores of these fungi. This applies either to the wetting with free water or exposure to atmospheric moisture and subsequent drying.

Basidiospores of *Lenzites sepiaria* gave a germination of 25 per cent after 2 years and 10 months of storage in an ice box; those of

L. trabea 50 per cent after 1 year; spores of *Trametes serialis* 2 per cent after 4 years and 3 months; those of *Fomes roseus* less than 1 per cent after 18 months; and those of *Lentinus lepideus* less than 1 per cent after 2 years and 7 months.

All but *Fomes roseus* have the ability to cast large numbers of spores and are shown to be capable of doing so within buildings. *Lenzites sepiaria* cast spores six times in experiments upon the ability of the sporophores to survive successive wetting, casting, and drying. A fruit body of *Trametes serialis* in the dark in the fungus pit cast spores for 15 days successively.

Observations upon fruit bodies of *Trametes serialis* in the bottom of a closed fungus pit showed that slight convection currents of air carried spores upward and throughout the pit. In mills, air currents caused by machinery, humidifiers, and heating pipes are of importance in disseminating spores cast into the air. Sow bugs were observed in this pit beneath the sporophores and were found to bear large numbers of the spores upon their bodies and appendages. The possible importance of insects and other animals in the dissemination of these wood-destroying fungi is suggested.

A description of the macroscopic and microscopic characters of malt-agar cultures of the fungi, with a key for identification, is given.

The cardinal temperatures for mycelial growth were found to be as shown in Table 5.

TABLE 5.—Cardinal temperatures for the growth of the mycelium of certain wood-destroying fungi.

Species.	Cardinal temperatures (° C.).		
	Minimum.	Optimum.	Maximum.
<i>Lenzites sepiaria</i>	About 8....	30 to 34....	Above 40.
<i>Lenzites trabea</i>.....	.....	28 to 30....	Little above 36.
<i>Trametes serialis</i>	About 3....	28.....	Between 32 and 37.
<i>Fomes roseus</i>	Below 4....	30.....	Above 36.
<i>Lentinus lepideus</i>	About 8....	28.....	Between 36 and 40.

Secondary spores of certain hymenomycetes have been reported by several writers as occurring naturally, and their importance in the economy of the fungi has been suggested. Studies were made upon the secondary spores of four of the fungi under consideration in view of their possible occurrence in a mill environment. Oidia and few chlamydospores were found in agar cultures of *Lenzites sepiaria*, and oidia also in wood cultures, and both kinds of spores in agar cultures of *L. trabea*. Chlamydospores were found in agar cultures of *Trametes serialis* and *Lentinus lepideus*.

Certain of the physiological relations of the oidia of *Lenzites sepiaria* and *L. trabea* and the chlamydospores of *Trametes serialis*

were studied. The germination temperatures corresponded closely with those of the basidiospores of the respective species except that the oidia germinated better at the higher temperature tried. Diffused light had no effect upon germination. Ten hours of direct sunlight in May prevented the germination of the secondary spores studied. Neither the oidia nor the chlamydospores resisted drying nor alternate wetting and drying.

The oidia of *Lenzites sepiaria* and *L. trabea* are essentially sticky and were found not to be adapted to dissemination by air currents. They are, however, adapted to dissemination by insects and water. This adaptation may possibly be of some importance in case oidia are found to produce naturally in mills. Thus far, however, the only secondary spores of these fungi found in mills are the chlamydospores of *Lentinus lepideus* upon the fruit bodies.

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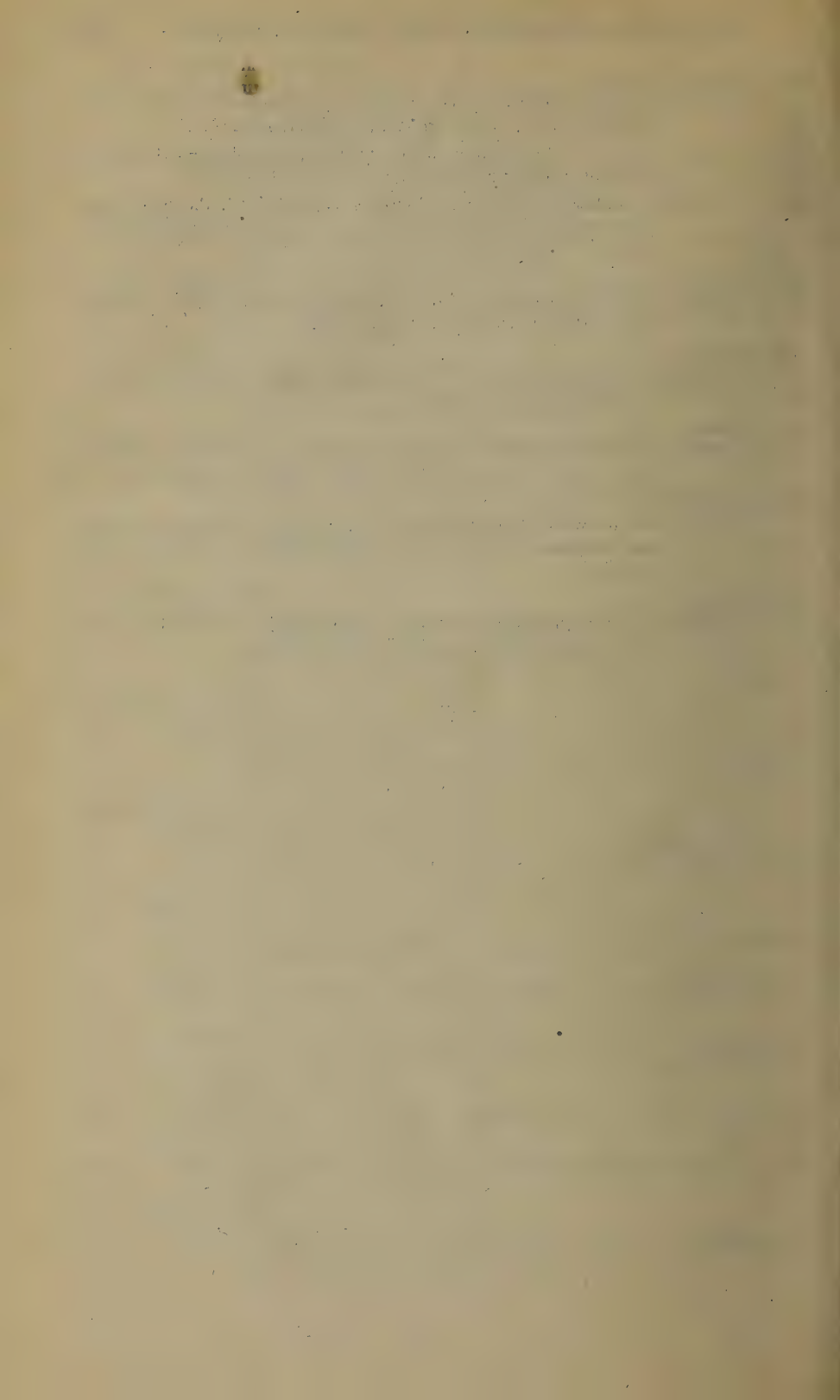
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THE WESTERN YELLOW PINE MISTLETOE:

Effect on Growth and Suggestions for Control.

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INTRODUCTION.

Western yellow pine (*Pinus ponderosa* Laws.) occurs naturally from southern British Columbia to northern Mexico and from the Pacific coast to east of the one hundredth meridian. It is found in the forests of every State west of the Great Plains and in many of them it is one of the most important and valuable forest trees. In the Southwest, western yellow pine is by far the most important timber tree, constituting over 80 per cent of the commercial forests of Arizona and New Mexico, approximately 30 billion board feet.

During the past 12 years studies have been in progress to determine the effect of the mistletoe (*Razoumofskyia cryptopoda* (Engelm.) Cov.) on the growth and seed production of western yellow pine. This parasite is the most widely distributed and one of the most

NOTE.—The author's names are in alphabetical order. The writers are indebted to Silviculturist G. A. Pearson, of the Fort Valley Experiment Station, for the permanent sample-plot data contained in Tables 11 and 17, for the data on the 1915 seed collection contained in Table 18, and for his general interest in the investigation.

serious enemies of the western yellow pine, and it has confronted the forester from the beginning of silvicultural practice in the Southwest. Especially on southern exposures and near the lower limit of the type, areas may be found on which fully 75 to 90 per cent of all the trees above 6 inches in diameter are infected with mistletoe.

In marking western yellow pine, there is often a question as to the advisability of cutting trees of various ages and degrees of mistletoe infection, or of allowing them to remain as seed trees and form a part of the future stand which will provide the basis for a subsequent cut. This problem involves not only a study of the effect of mistletoe on the rate of growth and the longevity of its host, but also of the effect of the parasitism on the amount and periodicity of seed production.

PHYSICAL AND CLIMATIC FEATURES OF THE REGION.

The areas in which the intensive studies were conducted lie within the Coconino and Tusayan National Forests on the Colorado Plateau, near the San Francisco Mountains in northern Arizona. The general topography of the plateau is rolling and consists of alternating flats comparatively free from rock and of rather low ridges which are very rocky. The underlying rock of the plateau consists principally of Coconino sandstone and Kaibab limestone overlaid by a lava flow of basalt and acidic volcanic rocks, mainly dacite, andesite, rhyolite, and latite, which constitute the main outcrops and surface rocks of the region. The soil varies widely from a fine sandy loam to a reddish friable clay, often containing an admixture of gravel and large volcanic boulders. In the greater part of the region northeast of the San Francisco Mountains the soil is covered with black volcanic cinders to depths varying from one-half inch to about 18 inches. Mistletoe infection is rare on these cinder areas and where found at all is light. The level mesas and lower slopes of the plateau, ranging from approximately 6,500 to 8,500 feet in elevation, are covered with a forest, of which approximately 95 per cent is western yellow pine, constituting the most extensive forest of this species in North America.

The climate of that portion of the Colorado Plateau which is covered with a western yellow pine forest is indicated by the climatological data which have been secured at the Fort Valley Forest Experiment Station. Pearson's¹ studies in this locality, together with the records of the United States Weather Bureau throughout the region, have shown that the climate is characterized by marked seasonal variations in precipitation, atmospheric humidity, and

¹ Pearson, G. A. A Meteorological Study of Parks and Timbered Areas in the Western Yellow Pine Forests of Arizona and New Mexico. *Monthly Weather Review*, vol. 41: 1615-1629, 1914.

wind movement, and great daily ranges of atmospheric temperature. The amount of sunshine is unusually high. The mean annual precipitation in the western yellow pine forest amounts to between 20 and 25 inches, which occurs in two well-defined periods during July and August in the form of thundershowers and from November to April in the form of snow. The period from about April 15 to July 15 is characterized by desiccating southwest winds and excessive evaporation, which, together with the small amount of precipitation, produce conditions adverse to most types of vegetation. The high rate of evaporation, low atmospheric humidity, and high wind velocity very often cause excessive transpiration from plants. The climatic and soil conditions are such that nowhere within the western yellow pine type of the Southwest does this species make rapid growth.

The influence of such climatological conditions is generally considered unfavorable to the best development of the host and favorable to the distribution and growth of the parasitic mistletoe. Weir² has emphasized the fact that the ecological relationships of the mistletoes, although they are parasitic, are similar to those of other chorophyllaceous plants in that they also respond to light, gravity, and certain chemical stimuli, while the marked variations in temperature to which the host readily responds are only slightly effective on the parasite. The low atmospheric humidity has a very slight influence on the xerophytic mistletoe, while the great amount of sunshine is favorable to the parasite. The unusually high winds of the Southwest frequently cause rather serious losses to western yellow pine stands in exposed situations through windfall, and the wind is known to aid in the dissemination of the mistletoe seed from tree to tree.

It follows that, where a virulent parasite responds favorably to its habitat, the host will rapidly deteriorate on the more unfavorable sites. From numerous observations made in various parts of the Southwest, it is apparent that a rather definite relation exists between the unfavorableness of the site and the degree of mistletoe infection. The percentage of infection and the resulting mortality of the host is usually higher on exposed dry ridges and south slopes than on the more favorable sites. This condition is very apparent on the Santa Fe National Forest in northern New Mexico.

THE WESTERN YELLOW PINE MISTLETOE.

The family Loranthaceæ has two genera in the United States, *Phoradendron* and *Razoumofskyia*. The species of *Phoradendron* are parasitic on both hardwoods and conifers, but mainly on hard-

² Weir, James R. The Larch Mistletoe: Some Economic Considerations of Its Injurious Effects. U. S. Dept. of Agri. Bul. 317, pp. 5-10, 1916.

woods, while the genus *Razoumofskyia* is found exclusively on conifers. Several species of the latter genus are rather common in the western United States and in some localities have become very serious parasites. *Razoumofskyia cryptopoda*, the western yellow pine mistletoe, is one of the most widely distributed of all the species, usually being found wherever the western yellow pine grows. (Pl. I, Fig. 1.)

Razoumofskyia cryptopoda flowers in Arizona and New Mexico during April and May, and the fruit matures in August and September of the next year. When the seeds begin to ripen, the berries gradually turn downward on their pedicels until the base of each berry when fully mature points upward. The gelatinous seeds when ripe are suddenly and forcibly ejected upward to a distance of several yards by the giving way of a ring of tissue situated near the base of the berry. This method of seed dissemination is common to all species of *Razoumofskyia*. Experiments and extended observations indicate that the aerial portions of both staminate and pistillate plants die and fall from the trees after one season of flowering and fruiting. (Pl. I, Fig. 2.)

EFFECT OF MISTLETOE ON GROWTH OF HOST.

The study of the effect of mistletoe on its host was accomplished (1) by periodic measurements and observations of standing trees, both infected and healthy; and (2) by detailed growth studies and observations of infected and healthy felled trees.

EFFECT ON BOLE OF TREE.

Ninety-one healthy and mistletoe-infected trees between 10 and 30 inches in diameter breast high on three different areas within a radius of 5 miles of the Fort Valley Experiment Station were tagged, numbered, measured, and mapped in 1910 with the object of determining the effect of mistletoe on the diameter and height-growth of the host, the diameter growth of limbs, and the growth of the merchantable contents of the bole. The diameters were measured with a diameter tape at 1, 4.5, 17, and 33 feet above the ground. The total heights were measured with a Forest Service standard hypsometer. The diameters of 20 healthy and 34 mistletoe-infected limbs falling in different infection classes were measured on 18 standing trees with a view of determining the effect of mistletoe on the growth of limbs. The points of measurement at 6 inches from the bole of the tree and every 6 inches beyond this point were marked by driving a 6-penny copper nail into the wood. All of the trees were remeasured in 1915 and were reclassified into four degrees of mistletoe infection, according to the prevalence of mistletoe on the tree, as follows: O, healthy trees without mistletoe; X, light



FIG. 2.—Advance of a mistletoe lesion on a twig of western yellow pine; dead stems of early infection in the center and young, vigorous mistletoe plants at the upper edge of the lesion.



FIG. 1.—A typical mistletoe colony on western yellow pine. The stems of dead and dying mistletoe plants are in the center and the youngest plants are seen at each end of the lesion.



mistletoe infection; XX, medium mistletoe infection; XXX, heavy mistletoe infection.

In order to check any material effect that the different crown classes might have on the rate of growth the trees were also classified, according to their dominance or relative position in the crown canopy of the group, into the following crown classes:

Isolated.—Trees growing in the open which do not form a contiguous part of the regular group canopy.

Dominant.—Trees with crowns extending above the general level of the group canopy and receiving full light from above and partly from the side; larger than the average trees in the group, and with crowns well developed but possibly somewhat crowded.

Codominant.—Trees with crowns forming the general level of the group canopy and receiving full light from above, but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

Intermediate.—Trees with crowns below, but still extending into the general level of the group canopy, receiving a little direct light from above but none from the sides, usually with small crowns considerably crowded on the sides.

Suppressed.—Trees with crowns below the general level of the group canopy and receiving no direct light either from above or from the sides; usually with small, poorly developed crowns.

There are two well-recognized forms of *Pinus ponderosa*, "black jack" and "yellow pine," based on age, rate of growth, and the resulting color of the bark. The term "black jack" applies to the young, vigorous trees under 125 to 150 years old which are characterized by a dark, almost black, or dark brown, narrow-furrowed bark. The "yellow pine" form comprises the older trees, which are characterized by a yellowish or reddish brown, widely furrowed bark. There is a marked difference in the form and volume of black jacks and yellow pines. The average black jack has a greater taper, a more rapid rate of growth, and approximately 10 per cent smaller cubic volume than the average yellow pine of the same diameter and height, which were the chief reasons for the segregation of black jacks and yellow pines.

The mean diameter growth or accretion of the standing black jacks for the 5-year period from 1910 to 1915, grouped according to degree of mistletoe infection, is shown in Table 1. The diameters were averaged by infection classes for each year mentioned, and the difference was computed as the growth during the 5-year period or the periodic accretion. The average growth per year during the period considered is termed the periodic annual accretion. The data show an almost consistent decrease in the diameter growth of black jack with the degree of mistletoe infection. The slight inconsistency exhibited in the rate of diameter growth of the *o* and *x* infection

classes might be explained by the fact that of the 27 trees in the infection class, 11 per cent were isolated trees which did not form a part of the forest canopy, 28 per cent were dominant, 57 per cent were codominant, and 4 per cent were intermediate trees, while with the x infection class 60 per cent were isolated trees which did not form a part of the forest canopy and 40 per cent were in the codominant crown class. Table 2 consistently shows a decrease in the rate of diameter growth of yellow pine which varies directly with the degree of mistletoe infection.

TABLE 1.—Comparison of the average diameter growth or accretion of 58 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of infection.	Diameter breast-high.		Accretion, 1910-1915.		Basis.
	1910	1915	Periodic.	Periodic Annual.	
	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Inch.</i>	<i>Trees.</i>
0.....	16.16	16.97	0.81	0.16	27
X.....	17.65	18.63	.98	.20	6
XX.....	15.82	16.57	.75	.15	15
XXX.....	14.24	14.36	.12	.02	10

TABLE 2.—Comparison of the average diameter growth or accretion of 33 standing yellow pines, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of infection.	Diameter breast-high.		Accretion, 1910-1915.		Basis.
	1910	1915	Periodic.	Periodic annual.	
	<i>Inches.</i>	<i>Inches.</i>	<i>Inch.</i>	<i>Inch.</i>	<i>Trees.</i>
0.....	24.60	25.30	0.70	0.14	9
X.....	25.56	26.04	.48	.10	8
XX.....	22.14	22.44	.30	.06	7
XXX.....	21.49	21.61	.12	.02	19

¹ Five trees of this class died during the 5-year period and were not included in the computation.

TABLE 3.—Comparison of total volume growth or increment of 58 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of infection.	Total volume.		Increment, 1910-1915.			Basis.
	1910	1915	Periodic.	Periodic annual.		
	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Per cent.</i>	<i>Trees.</i>
0.....	987.2	1,100.9	113.7	22.7	2.30	27
X.....	291.4	324.4	33.0	6.6	2.26	6
XX.....	434.0	470.6	36.6	7.3	1.68	15
XXX.....	234.9	243.2	8.3	1.7	.72	10

TABLE 4.—Comparison of the total volume growth or increment of 33 standing yellow pines, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of infection.	Total volume.		Increment, 1910-1915.			Basis.
	1910	1915	Periodic.	Periodic annual.		
	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Per cent.</i>	<i>Trees.</i>
O.....	1,151.0	1,226.0	75.0	15.0	1.30	9
X.....	1,206.0	1,250.0	44.0	8.8	.73	8
XX.....	706.0	725.0	19.0	3.8	.54	7
XXX.....	801.0	809.0	8.0	1.6	.20	19

¹ Five trees of this class died during the 5-year period and were not included in the computation.

Table 3 shows the total volume growth or increment of the standing black jacks for the same 5-year period, grouped by infection classes. The total volumes were computed by applying a volume table based on diameter and total height to the dimensions of each tree as measured in 1910 and 1915. It was found from taper measurements that volume tables could safely be applied to the individual trees. The volumes of all trees were totaled by infection classes. The difference between the total volumes at each time of measurement represents the periodic increment, and the average volume growth per year during the period considered is the periodic annual increment. Table 4 shows the increment of the standing yellow pines for the same 5-year period. Both forms of western yellow pine exhibit a consistent decrease in the increment of those trees which are infected with mistletoe varying directly with the degree of infection.

Bole measurements were made at 16-foot intervals to insure greater accuracy in the study of the effect of mistletoe on the growth of the merchantable contents of the bole of the tree. Table 5 gives a comparison of the diameter growth of the bole of 33 trees at 4.5, 17, and 33 feet above the ground. The comparative increments of the same trees are shown in Table 6. The apparent discrepancy between the rate of growth of the uninfected and lightly infected classes, as was noted above, is apparently due either to the varying proportions of the trees among the different crown classes or it may be possible that the infection at first results in a slight stimulation of the tree. In computing the volume, each section below the highest point of measurement was cubed as a cylinder by averaging the basal areas of the ends and multiplying by the length of the section;³ that portion above was considered as the top of the tree and its volume was computed as that of a cone.

The growth of the standing trees was further checked by complete stem analysis of 102 felled trees. Sections were examined as near to the surface of the ground as possible, at 4.5 feet above the ground,

³ This is known as the Smalian method. See Graves, Henry S., *Forest Mensuration*, pp. 91-93, New York, 1907.

and at every 8 feet above this point. The measurements were recorded by 5-year periods instead of by decades, as is the usual practice in complete stem analysis. The trees were selected as nearly as possible from the same site, kind of stand, and the same age and crown classes. Only those trees free from abnormalities or other possible causes of deterioration or conditions deterrent to their growth were studied, thus permitting only two variables to enter into the results, the age of the tree and the degree of mistletoe infection. The classification of the tree according to degree of infection represents the consensus of opinion of three different observers.

The basic data for each of the individual felled trees which were analyzed to show the effect of mistletoe on the growth and seed production of western yellow pine have been arranged in Table 7, according to the age of the trees. In compiling the stem analyses the data for each tree were computed separately. The diameters and heights of each tree for each fifth year, dating back from the year of analysis, were correlated with age in growth-analysis diagrams, from which the dimensions of each tree for each integral 5 years of age or quinquennium were read.

TABLE 5.—Comparison of the average diameter growth or accretion of 33 standing black jacks, for a 5-year period, at 4.5, 17, and 33 feet from ground, grouped according to degree of mistletoe infection.

Degree of infection.	Diameter outside bark.						Accretion, 1911-1916.						Basis.
	1911			1916			Periodic.			Periodic annual.			
	4.5 feet.	17 feet.	33 feet.	4.5 feet.	17 feet.	33 feet.	4.5 feet.	17 feet.	33 feet.	4.5 feet.	17 feet.	33 feet.	
o.....	In. 17.93	In. 15.28	In. 12.69	In. 19.03	In. 16.30	In. 13.71	In. 1.10	In. 1.02	In. 1.02	In. 0.22	In. 0.20	In. 0.20	Trees. 16
x.....	22.25	19.59	14.14	23.40	20.85	15.25	1.15	1.26	1.11	.23	.25	.22	4
xx.....	15.92	13.20	8.65	16.78	13.81	9.46	.86	.61	.81	.17	.12	.16	7
xxx.....	16.47	14.42	9.19	17.15	14.64	9.31	.68	.22	.12	.14	.04	.02	6

TABLE 6.—Comparison of the total volume growth or increment of 33 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of infection.	Total volume.		Increment, 1911-1916.			Basis.
	1911	1916	Periodic.	Periodic annual.		
	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Per cent.</i>	<i>Trees.</i>
O.....	919.76	1,047.40	127.64	25.53	2.78	16
X.....	359.07	410.65	51.68	10.32	2.87	4
XX.....	286.83	316.08	29.25	5.85	2.04	7
XXX.....	262.65	273.97	11.32	2.26	.86	6

TABLE 7.—Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine.

Tree number.	Age.	Diam-eter breast high.	Diam-eter growth for last 5 years.	Total height.	Height growth for last 5 years.	Total vol-ume.	Volume growth for last 5 years.	Deg-ree of infection. ¹	Crown class. ²	Aver-age length of leaves.	Aver-age length of leaf tufts.	Seed crop, 1915. ³
	Years.	Inch.	Inch.	Feet.	Feet.	Cu. ft.	Cu. ft.			Inch.	Inch.	
58.	23	4.0	1.5	15.5	4.5	1.81	0.39	o	X	5.5	19.3	O
75.	23	4.6	1.6	14.5	3.0	.84	.55	x	C	4.1	7.0	O
59.	24	2.8	.7	13.5	3.5	.27	.08	o	C	5.6	19.3	O
74.	24	3.2	1.0	13.5	3.5	.36	.17	o	C	5.1	11.6	O
67.	25	1.9	.4	9.0	1.0	.11	.03	xx	C	2.6	5.0	O
62.	26	2.4	.6	13.5	3.0	.22	.11	o	C	4.0	9.6	O
70.	26	2.0	1.0	11.5	3.5	.12	.06	o	D	5.1	8.0	O
85.	27	.....	.....	3.1	.5	.01	.001	xxx	X	3.0	3.2	O
72.	28	2.4	1.2	11.5	4.0	.19	.09	o	D	6.0	10.3	O
73.	28	6.2	1.8	24.5	4.5	2.02	.99	o	C	5.8	11.3	O
86.	28	.....	.....	3.2	.8	.021	.014	xxx	X	3.6	5.3	O
84.	29	.....	.....	2.8	.3	.009	.001	xxx	X	2.8	3.4	O
60.	30	5.4	.6	23.5	3.0	1.58	.47	x	D	4.1	10.0	O
69.	30	1.9	.4	9.5	2.0	.09	.01	x	I	3.3	4.3	O
71.	30	5.4	1.6	17.5	4.0	.88	.32	o	C	5.6	11.3	O
22.	30	4.8	1.8	17.5	4.5	.98	.53	o	D	5.6	23.3	O
65.	31	4.6	1.0	17.5	3.0	.80	.29	x	C	4.1	8.6	O
15.	31	.....	.....	3.5	1.0	.07	.06	x	X	3.8	9.3	O
68.	32	3.5	.2	10.5	1.0	.41	.13	xx	X	2.1	3.3	O
17.	33	.....	.....	3.0	.5	.01	.002	xx	X	.....	.....	O
61.	33	4.8	.5	16.0	1.5	1.06	.27	xxx	C	2.7	5.5	O
64.	33	3.0	.5	13.5	2.0	.33	.13	xx	I	3.3	10.3	O
63.	35	.5	.2	5.5	.5	.09	.02	xxx	I	2.3	3.0	O
66.	35	4.0	1.2	17.5	3.5	1.03	.42	x	C	4.1	8.6	O
83.	37	.....	.....	4.3	.7	.014	.002	xxx	X	3.1	2.8	O
107.	37	7.1	.....	21.0	.....	2.40	.....	o	D	5.2	8.5	O
18.	39	5.1	1.1	18.0	3.0	1.78	.69	o	X	5.3	13.0	O
20.	46	6.2	1.1	17.5	2.0	1.85	.63	xx	X	3.7	4.7	O
19.	53	6.2	.8	27.0	3.0	3.11	1.03	x	X	5.6	17.0	O
29.	60	15.6	1.5	47.5	3.5	21.24	5.05	o	X	6.8	13.3	O
47.	65	13.2	1.6	51.5	5.0	19.79	4.69	o	C	5.3	8.0	L
81.	65	10.8	1.3	46.0	4.5	11.22	3.38	o	C	5.8	22.3	O
82.	65	9.0	.4	33.0	1.5	5.09	.76	xxx	C	4.1	6.6	O
52.	66	11.2	.4	30.5	.5	8.14	.99	xx	X	3.5	5.0	O
89.	66	7.9	.7	33.5	2.5	3.35	.72	x	X	4.6	7.7	O
48.	69	10.8	1.1	39.0	2.5	9.09	2.11	xx	C	4.5	6.0	O
57.	70	15.8	2.0	60.0	5.0	27.38	6.12	o	O	6.3	7.3	L
80.	70	8.8	1.0	37.5	1.5	5.63	.94	o	S	6.6	7.5	O
88.	71	7.5	.6	34.5	1.5	4.29	.47	x	C	4.3	6.7	O
8.	72	4.4	.3	17.0	1.0	.85	.11	xx	I	5.6	.....	O
46.	72	15.6	1.1	43.5	3.0	19.84	3.59	o	X	5.1	10.6	O
37.	74	7.0	.1	20.0	1.0	1.66	.08	xxx	X	3.5	3.1	O
21.	75	7.4	.4	30.0	.5	3.77	.49	xxx	X	2.6	2.5	O
98.	76	19.5	1.5	60.5	3.5	40.70	4.79	o	C	5.0	6.7	O
10.	78	11.8	.4	36.5	.5	10.17	.67	xx	X	4.5	.....	O
77.	78	11.7	.5	38.5	.5	10.68	1.08	xxx	X	3.6	5.3	O
49.	79	9.5	.3	32.5	1.0	5.47	.53	xxx	C	4.0	4.6	O
78.	79	5.4	.4	26.0	1.0	2.08	.43	xx	S	3.5	4.3	O
104.	79	14.5	.....	42.0	.....	19.00	.....	o	X	3.8	6.2	L
1.	80	12.6	.2	39.5	.7	14.60	1.13	xxx	X	.....	.....	O
11.	80	10.8	1.5	34.5	3.5	7.82	2.21	o	X	6.3	18.0	O
103.	80	7.5	.....	20.0	.....	2.50	.....	xxx	X	2.8	4.2	O
5.	82	8.0	.4	33.5	.5	5.91	.33	xxx	C	.....	.....	O
9.	82	10.6	.2	44.5	.5	9.64	.43	xx	X	3.3	.....	O
44.	82	11.2	.6	39.0	2.5	9.07	1.56	x	C	4.3	5.0	O
90.	82	6.9	.3	28.5	.5	2.46	.36	x	C	4.3	5.3	O
6.	83	10.8	1.5	47.5	4.0	10.67	2.76	o	D	5.8	.....	O
38.	83	9.8	.2	37.5	.2	7.65	.30	xxx	X	3.3	5.0	O
105.	83	8.1	.....	26.0	.....	3.55	.....	xxx	C	3.5	4.2	O
106.	83	15.2	.....	49.0	.....	22.50	.....	o	C	5.5	6.1	L
54.	84	7.1	.5	27.5	2.0	2.51	.37	xxx	C	4.3	4.6	O
43.	85	8.2	.3	40.5	2.5	6.65	1.23	xx	C	4.1	5.0	O
51.	85	14.4	1.2	47.5	3.0	21.19	3.62	o	C	5.6	8.0	O
24.	87	11.1	1.6	41.5	4.0	10.93	2.84	o	X	6.0	22.0	O
79.	88	5.8	.4	24.5	.5	1.87	.23	xxx	S	4.1	5.6	O
14.	89	10.4	.5	35.5	2.0	7.84	.98	xxx	D	3.6	5.7	.....
53.	92	14.0	1.1	46.5	2.5	16.00	2.69	o	C	5.6	8.6	L
13.	93	7.8	.2	32.5	.5	4.26	.27	xx	X	5.1	7.8	O

¹ Degree of infection classified as follows: o = healthy trees without mistletoe, x = light mistletoe infection, xx = medium mistletoe infection, xxx = heavy mistletoe infection.² Crown class of trees classified as follows: X = isolated, D = dominant, C = codominant, I = intermediate, S = suppressed.³ Seed crop classified as follows: H = heavy, G = good, M = medium, L = light, O = none.

TABLE 7.—Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine—Continued.

Tree number.	Age.	Diam-eter breast high.	Diam-eter growth for last 5 years.	Total height.	Height growth for last 5 years.	Total volume.	Volume growth for last 5 years.	Degree of infection.	Crown class.	Average length of leaves.	Average length of leaf tufts.	Seed crop, 1915.
	Years.	Inch.	Inch.	Feet.	Feet.	Cu. ft.	Cu. ft.			Inch.	Inch.	
23.....	93	6.8	0.1	22.5	1.0	2.30	1.80	xxx	C	3.1	3.3	O
91.....	93	8.9	.4	36.0	1.0	5.65	1.01	x	X	4.5	6.5	O
2.....	94	12.0	1.5	40.5	1.0	15.18	4.40	o	X			O
42.....	94	14.8	.2	41.5	.5	20.03	.67	xxx	X	4.5	5.6	O
76.....	94	9.8	.7	39.0	1.0	7.80	.77	xxx	C	3.1	4.6	O
7.....	95	4.0	.1	21.0	1.0	.84	.16	xxx	S	4.1		O
56.....	95	14.4	.3	42.5	1.0	16.37	.42	xxx	C	4.0	5.0	O
87.....	97	9.0	.5	43.0	1.0	7.06	.85	x	C	4.6	5.3	O
28.....	98	18.1	1.5	64.5	6.0	47.49	6.48	x	X	6.3	11.3	O
25.....	100	8.3	.2	30.0	.5	4.23	.28	xxx	D	4.5	3.6	O
55.....	100	14.6	.2	49.5	1.0	20.05	1.08	xxx	C	5.2	5.5	O
99.....	102	20.6	1.0	64.5	3.0	52.44	6.81	o	C	4.7	6.3	O
12.....	104	12.4	.5	41.5	1.5	13.13	1.17	o	X	5.3	6.1	O
93.....	104	21.6	1.1	73.0	3.5	63.47	5.73	o	C	4.8	5.7	L
95.....	105	20.4	.8	60.5	1.5	62.11	4.30	x	C	5.2	7.2	O
40.....	106	9.4	.8	53.0	3.0	8.62	4.92	xx	C	5.3	6.6	O
39.....	112	11.6	1.2	62.0	3.5	18.82	5.59	o	C	5.0	10.6	O
96.....	114	18.8	.6	70.5	1.0	43.68	1.64	xx	C	4.3	6.8	O
94.....	117	20.4	1.0	78.0	3.0	69.85	5.05	o	C	5.1	6.2	L
45.....	120	19.4	.4	67.0	1.0	42.59	1.32	xx	o	4.3	3.6	O
97.....	120	22.4	1.7	79.5	2.5	83.56	11.32	o	C	5.4	6.8	L
41.....	121	11.9	.8	58.0	1.0	16.10	1.09	xxx	C	5.3	6.6	O
27.....	123	17.6	.1	46.5	.5	21.86	.58	xxx	X	4.6	5.1	O
4.....	124	20.2	1.7	68.5	1.0	67.68	9.40	o	X	6.0	9.0	O
92.....	125	17.1	.4	68.0	1.0	43.33	3.75	xx	C	5.1	5.0	O
3.....	126	20.3	.3	55.5	.3	42.03	1.49	xxx	X	4.0	2.5	O
50.....	130	23.4	2.3	79.5	1.5	92.78	8.56	o	D	5.0	8.3	M
26.....	134	18.2	.2	45.0	.5	25.23	.82	xxx	D	3.6	2.5	O
16.....	138	20.2	.4	59.5	.5	50.01	3.74	x	X	5.1	11.5	O
36.....	214	19.2	1.2	67.5	1.5	44.90	4.27	o	C	5.6	7.1	L
102.....	214	23.0	1.4	85.0	1.0	108.80	7.98	o	D	5.5	5.3	M
33.....	217	15.2	.5	58.5	1.0	32.92	2.62	xxx	X	4.7	8.3	O
30.....	218	18.2	.4	78.5	.2	59.68	2.55	xxx	C	3.5		L
100.....	218	20.8	.5	77.5	1.5	71.92	2.63	o	C	5.3	5.2	L
101.....	218	25.6	1.3	87.5	1.0	133.67	10.17	o	X	4.8	5.8	O
31.....	220	16.0	.1	84.5	.3	54.91	1.15	xxx	C	5.0	7.1	O
32.....	220	21.6	.8	87.5	1.0	90.26	7.06	o	D	5.8	7.3	M
34.....	230	25.6	.4	76.5	.3	107.47	2.88	xxx	X	5.2	8.8	O
35.....	233	17.6	.2	72.0	.5	65.10	5.68	xxx	C	4.5	5.6	O

Figure 1 shows the graphic growth analysis diagram for tree No. 4, a typical healthy western yellow pine, while Figure 2 shows the same kind of a diagram for tree No. 27, which was heavily infected with mistletoe. Both trees grew within a short distance of each other on the same site; they were of practically the same age and both belonged to the isolated crown class and the 101 to 140 year age class; therefore these factors can not be held accountable for the material falling off in the increment of the heavily infected tree. The very marked decrease in the rate of growth during the last 30 years, evidently due to the parasitism of the mistletoe, is very clearly shown by the closeness of the last seven quinquennial lines near the outside of the cone in Figure 2, which represents the growth of tree No. 27.

A set of curves was drawn for each tree showing the relation of age to diameter breast high, total height, and volume. This curving eliminated the irregularities and irrelevant abnormalities occurring in each tree. The data for the individual trees were then averaged by a series of harmonized curves for each infection and 40-year age

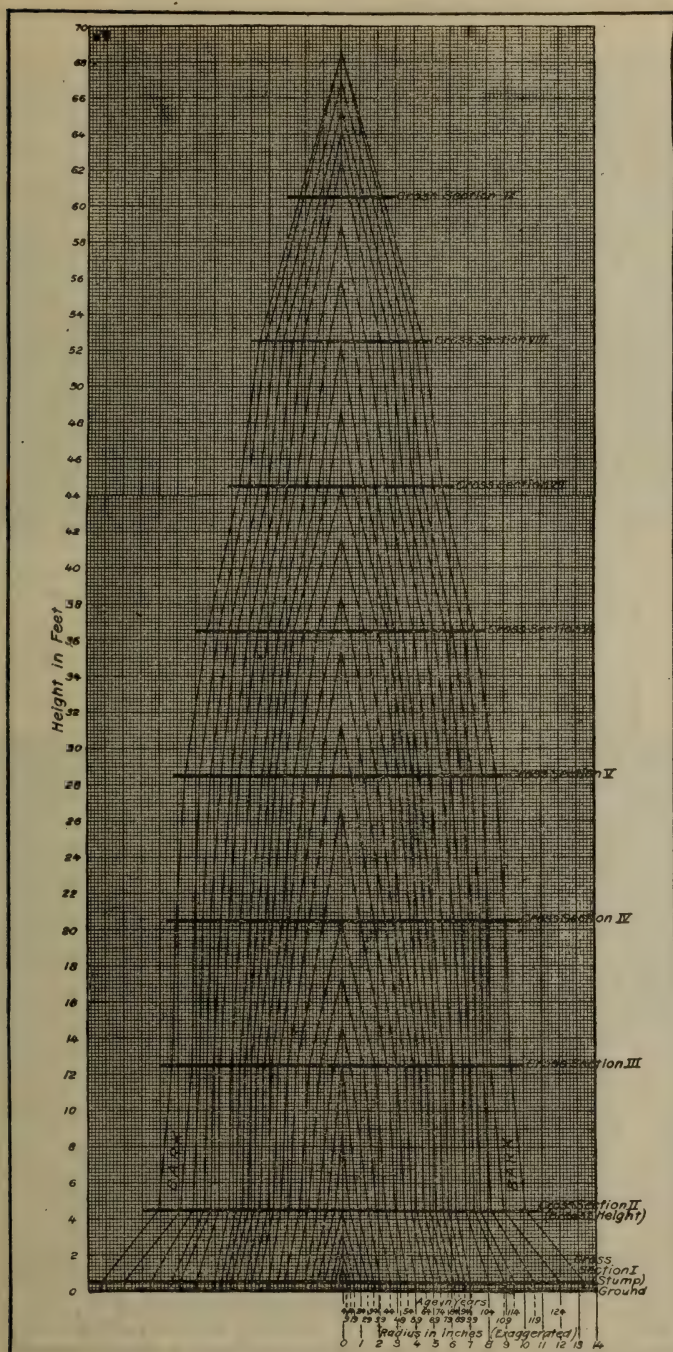


FIG. 1.—Graphic representation of the growth analysis of felled tree No. 4, a sound healthy western yellow pine. (Height greatly reduced in proportion to diameter.)

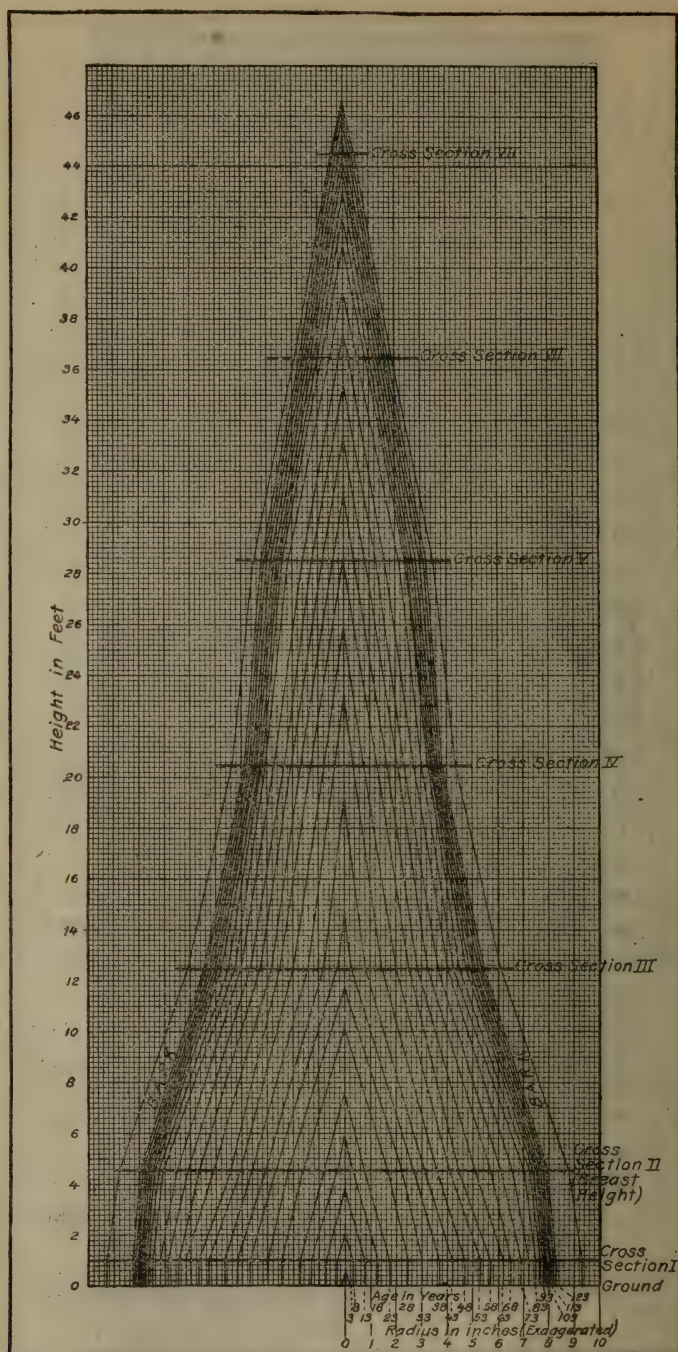


FIG. 2.—Graphic representation of the growth analysis of felled tree No. 27, a western yellow pine heavily infected with mistletoe. (Height greatly reduced in proportion to diameter.)

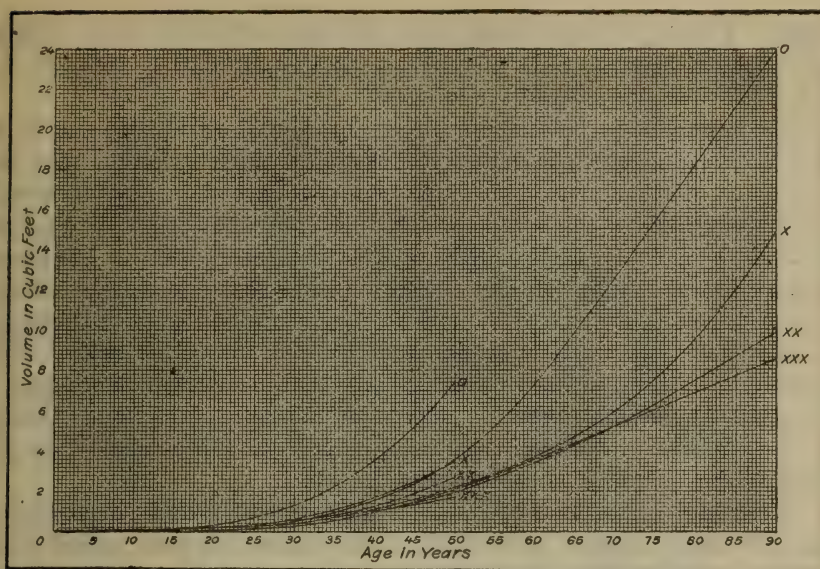


FIG. 3.—Volume-age curves showing the effect of the four degrees of mistletoe infection on the 21-60 and 61-100 year age classes.



FIG. 4.—Volume-age curves showing the effect of the different degrees of mistletoe infection on the 101-140 and the 201-240 year age classes.

class. Forty-year age classes were used instead of the usual 20-year age classes, because they provided a greater number of trees as the basis for each age and infection class.

The harmonized volume-age curves for the 21 to 60 and the 61 to 100 year age classes are shown in Figure 3, which indicates that the mistletoe infection was sufficiently severe to retard the rate of growth of the more heavily infected trees of these two age classes by approximately 20 years. Figure 4 shows a similar retardation of the increment for the 101 to 140 and the 201 to 240 year age classes, except that the rate of growth of the more heavily infected trees of these age classes has been on the decline for the past 70 to 80 years. The curves in both figures show conclusively that the current increment is directly dependent upon the degree of mistletoe infection. Generally speaking, the degree of mistletoe infection increases with the length of time which a tree has been infected.

A further comparison of the average diameter growth or accretion of the felled western yellow pine trees for the 25-year period from 1890 to 1915, grouped by 40-year age classes and degree of mistletoe infection, is shown in Table 8. A similar comparison of the average height growth or accretion of the same trees is given in Table 9. Table 10 shows a comparison of the average volume growth or increment of the same trees for the same period, similarly grouped by age and infection classes. The 21 to 60, 61 to 100, and the 101 to 140 year age classes in Tables 8, 9, and 10 are composed entirely of black jacks, while yellow pines constitute the 201 to 240 year age class.

TABLE 8.—Comparison of the average diameter growth or accretion of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.

Age class.	Degree of infection.	Diameter breast high.		Accretion, 1890-1895, periodic annual.	Diameter breast high, 1900.	Accretion, 1895-1900, periodic annual.	Diameter breast high, 1905.	Accretion, 1900-1905, periodic annual.	Diameter breast high, 1910.	Accretion, 1905-1910, periodic annual.	Diameter breast high, 1915.	Accretion, 1910-1915, periodic annual.	Basis.
		1890	1895										
<i>Years.</i>		<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>Trees.</i>
21 to 60.....	0	0.8	1.0	0.04	1.6	0.12	2.3	0.14	3.7	0.28	5.0	0.26	11
	X	.2	.6	.08	1.4	.16	2.5	.22	3.5	.20	4.4	.18	6
	XX	.1	.4	.06	.8	.08	1.3	.10	1.8	.10	2.1	.06	7
	XXX	.....	.3	.06	.6	.06	.7	.02	.9	.04	1.1	.04	5
61 to 100....	0	7.2	8.2	.20	9.3	.22	10.4	.22	11.5	.22	13.0	.30	12
	X	6.6	7.3	.14	8.0	.14	8.7	.14	9.3	.12	9.9	.12	7
	XX	6.0	6.8	.16	7.5	.14	8.1	.12	8.6	.10	9.0	.08	9
	XXX	6.8	7.5	.14	8.2	.14	8.7	.10	9.2	.10	9.4	.04	17
101 to 140...	0	15.0	15.7	.14	16.5	.16	17.5	.20	18.6	.22	19.8	.24	6
	X	14.5	15.1	.12	15.9	.16	16.7	.16	17.5	.16	18.3	.16	4
	XX	14.8	15.2	.08	15.7	.10	16.1	.08	16.5	.08	16.9	.08	6
	XXX	15.2	15.6	.08	15.9	.06	16.3	.08	16.7	.08	17.0	.06	4
201 to 240...	0	17.8	18.5	.14	19.3	.16	20.1	.16	21.1	.20	22.1	.20	5
	XXX	16.7	17.0	.06	17.4	.08	17.7	.06	17.9	.04	18.2	.06	5

TABLE 9.—Comparison of the average height growth or accretion of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.

Age class.	De- gree of in- fec- tion.	Total height.		Ac- cretion 1890- 1895, peri- odic annual	Total height, 1900.	Ac- cretion 1895- 1900, peri- odic annual	Total height, 1905.	Ac- cretion 1900- 1905, peri- odic annual	Total height, 1910.	Ac- cretion 1905- 1910, peri- odic annual	Total height, 1915.	Ac- cretion 1910- 1915, peri- odic annual	Basis.
		1890	1895										
<i>Years.</i>		<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Trees.</i>
21 to 60.....	o	3.2	5.4	0.44	8.0	0.52	11.3	0.66	14.9	0.72	18.6	0.74	11
	x	2.6	5.1	.50	8.3	.64	12.2	.78	15.3	.62	18.2	.58	6
	xx	1.6	3.2	.32	4.6	.28	6.1	.30	7.4	.26	8.6	.24	7
	xxx	1.3	2.5	.24	3.8	.26	4.9	.22	5.7	.16	6.3	.12	5
61 to 100....	o	27.4	31.5	.82	35.6	.82	39.5	.78	43.2	.74	46.6	.68	12
	x	29.6	32.2	.52	34.6	.48	36.8	.44	38.8	.40	40.8	.40	7
	xx	23.7	26.1	.48	28.3	.44	30.5	.44	32.1	.32	33.3	.24	9
	xxx	23.4	28.4	.40	30.0	.32	31.2	.24	32.2	.20	33.0	.16	17
101 to 140...	o	58.9	61.5	.52	64.2	.54	66.9	.54	69.7	.56	72.5	.56	6
	x	49.4	51.8	.48	53.5	.34	55.0	.30	56.4	.28	57.5	.22	4
	xx	55.8	57.9	.42	60.0	.42	61.9	.38	63.5	.32	65.0	.30	4
	xxx	46.4	47.8	.28	49.0	.24	50.0	.20	50.6	.12	51.2	.12	4
201 to 240...	o	75.5	76.7	.24	77.8	.22	78.9	.22	80.0	.22	81.2	.24	5
	xxx	71.4	72.0	.12	72.5	.10	73.0	.10	73.5	.10	74.0	.10	5

TABLE 10.—Comparison of the average volume growth or increment of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.

Age class.	De- gree of in- fec- tion.	Total volume.		Increment, 1890-1895.		Total volume.	Increment, 1895-1900.		Total volume.
		1890.	1895.	Periodic annual.		1900.	Periodic annual.		1905.
<i>Years.</i>		<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Per cent. (1)</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Per cent. (1)</i>	<i>Cubic feet.</i>
21 to 60.....	o	0.36	0.54	0.036		0.80	0.052		1.19
	x	.02	.05	.006		.20	.030		.41
	xx	.01	.02	.002		.08	.012		.14
	xxx					.04	.008		.08
61 to 100.....	o	3.77	5.40	.326	8.6	7.54	.428	7.9	10.23
	x	4.90	5.91	.202	4.1	7.10	.238	4.0	8.49
	xx	2.53	3.24	.142	5.6	3.98	.148	4.6	4.81
	xxx	4.12	4.94	.164	4.0	5.72	.156	3.2	6.46
101 to 140.....	o	35.10	39.78	.936	2.7	44.80	1.004	2.5	50.26
	x	25.95	30.15	.840	3.2	34.80	.930	3.1	39.20
	xx	23.72	26.35	.526	2.2	28.62	.454	1.7	30.75
	xxx	20.02	21.04	.204	1.0	22.87	.366	1.7	24.10
202 to 240.....	o	59.06	63.94	.976	1.7	69.38	1.088	1.7	75.72
	xxx	52.16	54.36	.440	.8	56.56	.440	.8	58.94

Age class.	De- gree of in- fec- tion.	Increment, 1900-1905.		Total volume.	Increment, 1905-1910.		Total volume.	Increment, 1910-1915.		Ba- sis.
		Periodic annual.		1910.	Periodic annual.		1915.	Periodic annual.		
<i>Years.</i>		<i>Cubic feet.</i>	<i>Per cent. (1)</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Per cent. (1)</i>	<i>Cubic feet.</i>	<i>Cubic feet.</i>	<i>Per cent. (1)</i>	<i>Trees.</i>
21 to 60.....	o	0.078		1.81	0.124		2.67	0.172		11
	x	.042		.86	.090		1.25	.078		6
	xx	.012		.24	.020		.37	.026		7
	xxx	.008		.18	.020		.29	.022		5
61 to 100.....	o	.538	7.1	13.52	.658	6.4	17.28	.752	5.6	12
	x	.278	3.9	9.89	.280	3.3	11.49	.320	3.2	7
	xx	.166	4.2	5.65	.168	3.5	6.52	.174	3.1	9
	xxx	.148	2.6	7.12	.132	2.0	7.70	.116	1.6	17
101 to 140.....	o	1.092	2.4	56.48	1.244	2.5	63.41	1.386	2.5	6
	x	.880	2.5	43.72	.904	2.3	48.07	.870	2.0	4
	xx	.426	1.5	32.70	.390	1.3	34.60	.380	1.2	4
	xxx	.246	1.1	25.32	.244	1.0	26.42	.220	.9	4
201 to 240.....	o	1.268	1.8	82.46	1.348	1.8	90.12	1.532	1.9	5
	xxx	.476	.8	61.38	.488	.8	64.00	.524	.9	5

¹ The periodic annual increment per cent was not computed for the 21 to 60-year age class because of the extremely small initial volumes and the proportionately great effect on the percentage of slight individual variations.

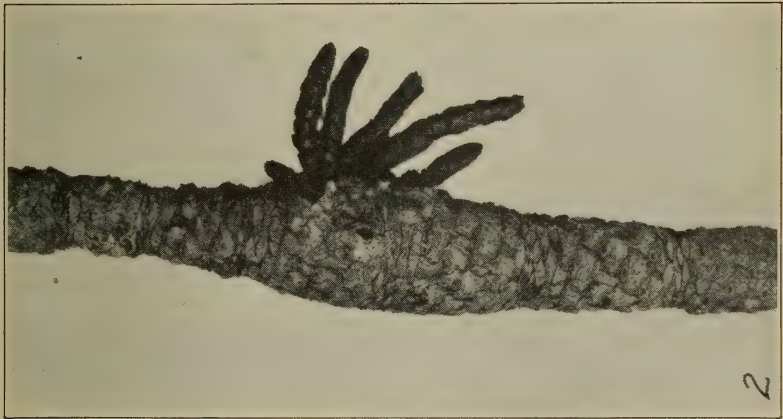
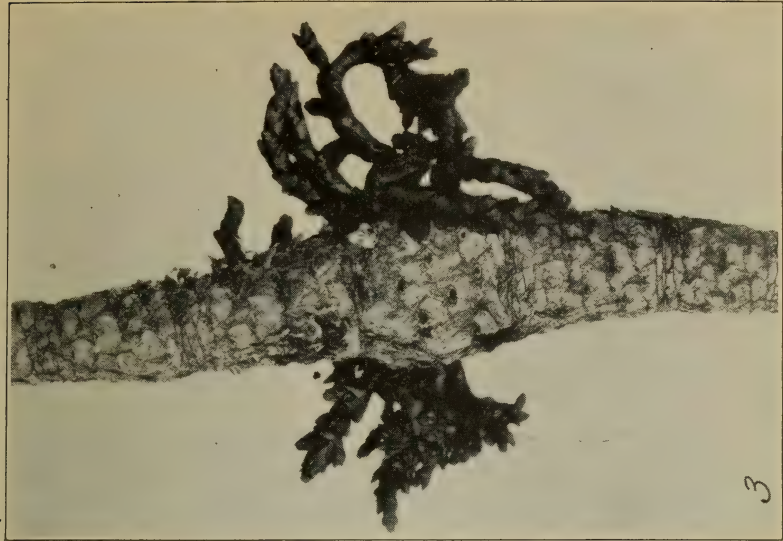
In the early stages of the study the trees were segregated by crown classes. Since by far the greater part of the trees in the open park-like stands studied were in the isolated, dominant, and codominant classes, the effects of crown class were found to be negligible in contrast to the marked effect of mistletoe in retarding the rate of growth. The retardation of growth due to the mistletoe was consistently evident in each age-crown class in which sufficient trees were secured to form a comparable basis. It was impossible to secure an equal number or equal proportion of each crown class in each age-infection class. As has been shown, it was found more necessary to segregate the felled trees by age-infection classes than by crown-infection classes. It was impracticable to segregate by crown classes all of the trees used in this study because of the extremely small number and in some cases entire lack of trees falling into each age-infection-crown class, had such a triple classification been used. The diameter, height, and volume growth during the 5-year period, 1910-1915, in the 21 to 60 year age class of the isolated trees included in Table 7, may be cited to show the injurious effect of mistletoe on growth within a given age-crown class, as follows:

Degree of infection.	Breast high diameter growth for last 5 years.	Height growth for last 5 years.	Volume growth for last 5 years.	Basis.
	<i>Inches.</i>	<i>Feet.</i>	<i>Cubic feet.</i>	<i>Trees.</i>
0.....	1.3	3.3	2.04	3
x.....	.8	2.0	.54	2
xx.....	.6	1.2	.25	3
xxx.....	(1)	.5	.004	4

¹ The trees in this class were less than 4.5 feet in height.

In Table 11 is shown increment data for two intensive sample plots aggregating 24 acres, located within the extensive plot on the Tusayan National Forest mentioned below, the data being grouped according to degree of infection. An accelerated growth is noted in the x infection class comparable to that noted in Table 1, the explanation of which is not evident from the data at hand, unless it be an actual stimulation due to the presence of the mistletoe. The decrease in the rate of growth in the heavily infected class is very marked and is in accord with all of the other results secured in this study.

Two seedlings, one healthy and the other heavily infected with mistletoe, which were growing side by side on a good site, were analyzed and both found to be 15 years old. The healthy seedling showed marked vigor and was 4 feet tall, whereas the one infected with mistletoe was only 3 feet tall and showed evident stunting and that death was imminent.



Three successive stages in the early development of mistletoe on twigs of western yellow pine and the formation of swellings by mistletoe.



FIG. 1.—A western yellow pine tree showing stunted branches and witches' brooms in the lower part of the crown caused by mistletoe. Santa Fe National Forest, New Mexico.

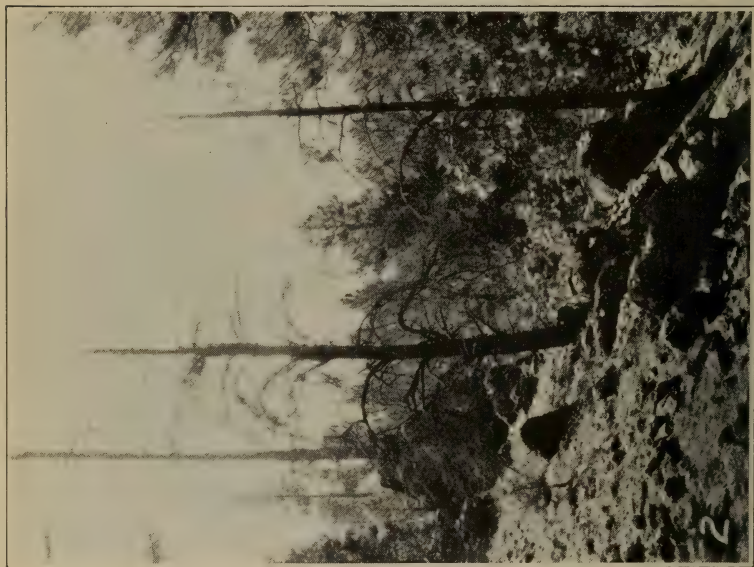


FIG. 2.—Two "black jacks" in the foreground and a "yellow pine" in the background killed by mistletoe. The "black jacks" were killed recently while the "yellow pine" has been dead for a number of years. Coconino National Forest, Arizona.



FIG. 3.—A western yellow pine tree recently killed by mistletoe. Coconino National Forest, Arizona.

The data presented in the preceding pages show that, although minor fluctuations are exhibited, the rate of growth of the host decreases with the amount of mistletoe infection; or, in other words, is dependent on the degree of parasitism. Possible exceptions may be cases of very light infection which appear to act as stimulants for the host tree. These results are really to be expected when the effects of mistletoe parasitism are fully understood.

TABLE 11.—*The effect of mistletoe infection on the rate of growth of western yellow pine on two intensive sample plots aggregating 24 acres on the Tusayan National Forest.*

Degree of infection.	Average diameter growth, 1914-1919.	Periodic annual increment, 1914-1919.	Periodic annual increment, 1914-1919. ¹	Total volume of class, 1919.	Basis (number of trees, 4 inches and over d. b. h.).
	<i>Inches.</i>	<i>Cubic feet.</i>	<i>Per cent.</i>	<i>Cubic feet.</i>	
0.....	0.70	4.56	2.54	1,636.2	359
x.....	.88	5.65	2.79	553.9	98
xxx.....	.49	2.23	1.83	254.5	114

¹ On cubic-foot basis.

NOTE.—Since there were only 13 trees classed as moderately infected, they were omitted because of the small basis.

EFFECT ON LIMBS.

The first visible effect of the infection of a limb by mistletoe is the formation of a fusiform swelling (Pl. II) about the center of infection similar to those occasionally found on stems. This hypertrophy is the first stage of a later abnormal growth of branches from the enlarged portion, which results in the formation of witches' brooms. (Pl. III, Fig. 1.) When the stimulus of the parasite has once become manifest through the formation of a broom, the tendency toward abnormal branching continues, although the aerial parts of the mistletoe have may died.

The comparative diameter growth or accretion of 54 limbs on 18 standing black jacks is averaged by infection classes in Table 12. Measurements were taken at 6 inches from the bole of the tree and at 6-inch intervals beyond this point. The measurements taken at 6 to 18 inches from the bole of the tree were averaged and are presented in the table to facilitate a clearer and more comprehensive interpretation of the significant data. Limb measurements were also taken on the felled trees to check the comparative growth of the healthy and mistletoe-infected limbs of the standing trees. From these data, which are summarized in Table 13, it is apparent that the limbs had been infected at least 25 years prior to the time at which they were analyzed. The data presented in both tables show that, for the limbs examined, the rate of growth in diameter of limbs infected with mistletoe is greater than that of uninfected limbs. It is

very probable that the increased diameter growth continues to a certain point, beyond which there is a pronounced decrease in the rate of growth, until the limb eventually dies. This increased diameter growth is probably caused by the formation of an excessive amount of pathological parenchyma tissue, as a result of the irritation of the cambium by the parasite. The softer parenchyma adjacent to the center of infection renders the infected wood somewhat weaker than the more highly-lignified tissues of normal, uninfected wood. The presence of the mistletoe in the limb produces a stimulated growth of the host near the center of infection.

TABLE 12.—*Comparison of the average diameter growth or accretion of 54 limbs on 18 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Average diameter. ¹		Accretion, 1910-1915.		Basis.
	1910	1915	Periodic.	Periodic annual.	
	Inches.	Inches.	Inch.	Inch.	Limbs.
0.....	3.84	3.98	0.14	0.028	20
X.....	3.90	4.06	.16	.032	6
XX.....	4.35	4.62	.27	.054	7
XXX.....	4.08	4.46	.38	.076	21

¹ Average of two sets of measurements taken at 6 and 18 inches from the bole of the tree.

TABLE 13.—*Comparison of the average diameter growth or accretion of 8 limbs on 4 felled western yellow pine trees, for a 25-year period, grouped according to degree of mistletoe infection.*

Degree of infection.	Average diameter. ¹		Accretion, 1890-1895.	Average diameter. ¹	Accretion, 1895-1900.	Average diameter. ¹	Accretion, 1900-1905.	Average diameter. ¹	Accretion, 1905-1910.	Average diameter. ¹	Accretion, 1910-1915.	Basis
	1890	1895	Periodic annual.	1900	Periodic annual.	1905	Periodic annual.	1910	Periodic annual.	1915	Periodic annual.	
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	Limbs
0.....	1.68	1.84	0.032	2.01	0.034	2.21	0.040	2.34	0.026	2.46	0.024	4
XXX.....	3.06	3.32	.052	3.68	.072	4.04	.072	4.34	.060	4.56	.044	4

¹ Average of two sets of measurements taken at 6 and 18 inches from the bole of the tree.

Eccentricities, especially hyponastic growth, are considerably more pronounced in limbs heavily infected with mistletoe than in healthy limbs. The formation of a large witches' broom produces an abnormally heavy load which must be borne by that portion of the limb nearest to the bole of the tree. This abnormal load produces stresses sufficient to stimulate the formation of wood on the under side of the limbs through the deposition of food materials, which enables the wood to withstand the compression below. The tension above is over-

come by the development of a special tissue on the upper side of the limb.

The increased size of the limbs infected with mistletoe renders limbing and brush disposal in logging operations more difficult and consequently more expensive. The excessive secretion of resin which occurs in mistletoe-infected limbs has somewhat the same effect on brush disposal.

HYPERTROPHY AND RESIN FLOW.

Although mistletoe infection causes swellings on both branches and trunks, the stem swellings frequently become less noticeable as the tree grows. In many cases there are no pronounced swellings on the larger boles even when very old mistletoe infections are present, about the only means of detecting the infection being the presence of the mistletoe or the unusual roughness of the bark. (Pl. IV, Fig. 1.) When, however, infection occurs during the early life of the tree, it frequently results in the formation of a burl which may attain very conspicuous proportions. The fusiform swellings on both the stems and limbs resulting from mistletoe infections are centers where abnormal amounts of food materials are stored, which condition is evidently stimulated by the decided pathogenic tendencies of the mistletoe. The cortex is frequently gnawed from the lesions by rodents, especially porcupines and squirrels, attracted by the soft spongy nature and the greater thickness of the inner bark of mistletoe-infected branches and stems. This fact establishes a casual relationship between mistletoe infection and rodent injury.

As previously stated, there is more or less hypertrophy at the point of mistletoe infection on both limbs and stems. This hypertrophy is frequently accompanied by a copious flow of resin, which appears as small drops, usually on the lower side of limbs, which are heavily infected with mistletoe. A cross section through such a limb shows large areas of the sapwood thoroughly infiltrated with resin. The process of infiltration continues on many of the limbs until the fibro-vascular system is thoroughly clogged with resin; the limb is girdled as far as receiving any food supply is concerned, and is finally killed. This process is usually very gradual, but none the less sure.

The resin flow from such mistletoe-infected limbs is not caused by insect punctures. A careful examination of the resin-infiltrated areas fails to show any signs of such injury. On many of the trees which are heavily infected with mistletoe, resin cankers (Pl. IV, Fig. 2) of varying sizes are found on the bole. These cankers are often directly associated with local mistletoe infection. The resin flows on the bole are usually indicative of the decline of the tree; in fact, trees with marked resin-flow cankers usually die in a relatively short time.

EFFECT ON THE FOLIAGE.

Tables 14, 15, and 16 show the effects of the mistletoe on the foliage of the western yellow pine. The data included in Table 16 were obtained as follows:

Each tree crown was divided into three divisions—bottom, middle, and top—including in each division about one-third of the total leaf surface. One hundred tufts from each section were selected at random and measured; the mean length of these tufts was taken as the average length per tuft for that section. Then 10 tufts of this average length were taken from each of the three sections into which the crown had been divided. These tufts, 30 in all for each tree, were cut off and taken to the laboratory, where the number of leaves per tuft, the length, and the width of each leaf were determined. The total number of tufts in the bottom, middle, and top thirds was determined by actual count. The number of tufts thus obtained was multiplied by the average number of leaves found in the 10 tufts from each section. This gave the average number of leaves in each section. The sum of the leaves in the three sections gave the average number of leaves in any given tree crown.

TABLE 14.—Comparison of the length of leaves of 103 western yellow pine trees, classified according to degree of mistletoe infection.

Degree of infection.	In lower portion of crown.			In central portion of crown.			In upper portion of crown.			Mean for entire crown.			Basis.
	Mean minimum.	Mean Maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	
0.....	In. 3.3	In. 6.2	In. 4.9	In. 3.8	In. 6.3	In. 5.5	In. 4.2	In. 6.9	In. 5.8	In. 3.8	In. 6.5	In. 5.4	Trees. 38
x.....	2.3	5.3	4.0	2.5	5.9	4.5	3.3	6.2	5.0	2.7	5.8	4.5	15
xx.....	2.1	5.3	3.8	2.5	5.4	4.1	2.9	5.7	4.6	2.5	5.5	4.2	18
xxx.....	2.1	5.1	3.6	2.4	5.1	4.0	2.7	5.1	4.0	2.4	5.1	3.9	32

TABLE 15.—Comparison of the length of leaf tufts of 97 western yellow pine trees, classified according to degree of mistletoe infection.

Degree of infection.	In lower portion of crown.			In central portion of crown.			In upper portion of crown.			Mean for entire crown.			Basis.
	Mean minimum.	Mean Maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	Mean minimum.	Mean maximum.	Average.	
0.....	In. 3.4	In. 11.5	In. 6.7	In. 5.4	In. 15.5	In. 10.0	In. 6.8	In. 22.7	In. 13.8	In. 5.2	In. 16.6	In. 10.2	Trees. 37
x.....	3.0	10.1	6.5	4.0	12.0	8.0	5.5	16.8	10.3	4.2	13.0	8.3	15
xx.....	2.4	8.2	4.9	2.3	9.1	5.2	3.4	11.1	7.3	2.7	9.4	5.8	15
xxx.....	2.3	8.1	4.5	2.6	8.6	5.0	2.4	8.5	4.8	2.4	8.4	4.8	30

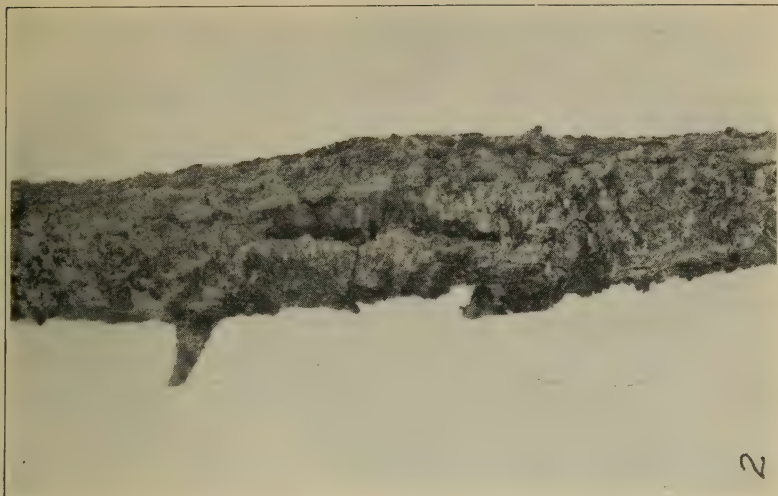


FIG. 2.—A resin canker developing in an old mistletoe lesion on western yellow pine.

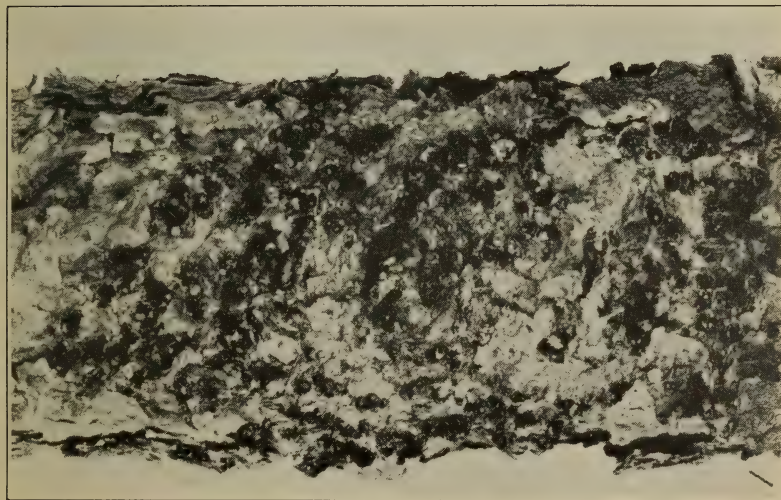


FIG. 1.—Concentric rings of advance of a mistletoe lesion on western yellow pine.

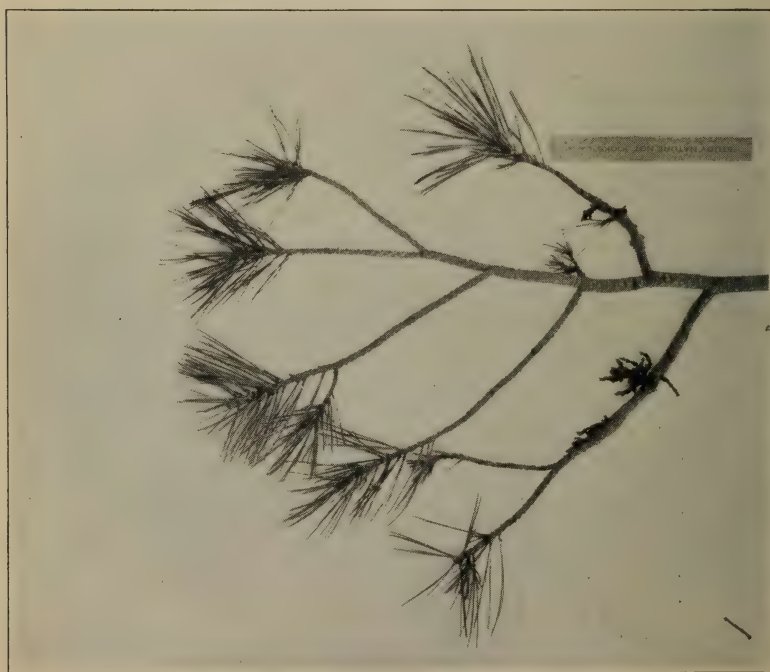


FIG. 1.—A small branch of western yellow pine showing fewer and smaller leaves and shorter internodes due to the mistletoe, of which three local infections may be seen. One-sixth natural size.



FIG. 2.—A small branch of western yellow pine showing the larger leaves and longer internodes developed on a healthy tree in the same group from which the branch shown in Figure 1 was secured. One-eighth natural size.

TABLE 16.—*The effects of mistletoe on the photosynthetic surface of western yellow pine.*

Tree number.	Degree of infection.	Age.	Diameter breast high outside bark.	Total height.	Total volume.	Crown.		Crown class.
						Width.	Length.	
		Years.	Inches.	Feet.	Cubic feet.	Feet.	Feet.	
103.....	xxx	80	7.5	20.0	2.50	10.0	15.5	X
104.....	o	79	14.5	42.0	19.00	17.0	32.0	X
105.....	xxx	83	8.1	26.0	3.55	8.5	18.5	C
106.....	o	83	15.2	49.0	22.50	22.0	42.0	C
107.....	o	37	7.1	21.0	2.40	12.0	18.0	D

Length of leaf tufts.

Tree number.	Lower portion of crown.				Center of crown.				Upper portion of crown.				Mean for entire crown.		
	Minimum.	Maximum.	Average.	Number of tufts.	Minimum.	Maximum.	Average.	Number of tufts.	Minimum.	Maximum.	Average.	Number of tufts.	Minimum.	Maximum.	Average.
	In.	In.	In.		In.	In.	In.		In.	In.	In.		In.	In.	In.
103.....	0.5	7.0	3.2	81	1.0	8.0	3.8	329	1.0	12.0	5.7	234	0.8	9.0	4.2
104.....	1.0	11.3	5.3	2,161	2.0	13.0	5.4	2,390	2.0	18.0	8.0	1,151	1.6	14.1	6.2
105.....	.3	11.0	3.7	242	.5	12.0	4.0	183	.6	13.0	5.0	176	.4	12.0	4.2
106.....	1.0	11.0	4.0	1,522	1.5	17.0	6.7	1,228	2.0	26.0	7.7	445	1.5	18.0	6.1
107.....	1.5	12.5	6.8	379	2.5	18.0	8.8	321	2.5	28.0	10.0	313	2.1	19.5	8.5

Tree No.	Total number of tufts in entire crown.	Length of leaves.									
		Lower portion of crown.				Center of crown.					
		Mean minimum.	Mean maximum.	Mean average.	Number of leaves.	Mean minimum.	Mean maximum.	Mean average.	Number of leaves.		
		In.	In.	In.		In.	In.	In.			
103.....	644	1.6	3.3	2.6	13,122	1.7	3.5	2.6	62,181		
104.....	5,702	2.5	4.9	3.5	518,640	2.8	5.1	3.7	803,040		
105.....	601	2.0	4.1	3.2	109,142	2.3	4.2	3.1	67,161		
106.....	3,195	4.1	5.8	4.9	365,280	4.4	6.7	5.7	289,808		
107.....	1,013	3.3	5.2	4.5	94,371	4.1	5.7	5.1	172,972		

Tree No.	Length of leaves.							
	Upper portion of crown.				Mean for entire crown.			
	Mean minimum.	Mean maximum.	Mean average.	Number of leaves.	Mean minimum.	Mean maximum.	Mean average.	
	In.	In.	In.		In.	In.	In.	
103.....	1.8	4.5	3.2	84,240	1.7	3.7	2.8	
104.....	2.8	5.1	4.1	470,759	2.7	5.0	3.7	
105.....	3.1	5.0	4.3	85,712	2.4	4.4	3.5	
106.....	4.8	6.8	5.9	182,005	4.4	6.4	5.5	
107.....	5.2	6.4	5.9	152,431	4.3	5.7	5.1	

TABLE 16.—*The effects of mistletoe on the photosynthetic surface of western yellow pine—Continued.*

Tree No.	Total number of leaves in entire crown.	Leaf surface.				Ratio of leaf surfaces.	Ratio of volumes. ¹
		Lower portion of crown.	Central portion of crown.	Upper portion of crown.	Entire crown.		
		<i>Square inches.</i>	<i>Square inches.</i>	<i>Square inches.</i>	<i>Square inches.</i>		
103.....	159,543	4,094.1	19,400.4	32,348.2	55,842.7	1.0	1.0
104.....	1,792,439	217,828.8	356,549.8	231,613.4	805,992.0	14.4	7.6
105.....	262,015	40,910.5	24,983.9	44,427.4	110,321.8	2.0	1.4
106.....	837,093	218,438.4	198,228.7	128,939.5	545,606.6	9.8	9.0
107.....	419,774	50,960.3	105,868.9	107,921.4	264,750.6	4.7	.96

¹ In these ratios Tree No. 103 is taken as unity.

The average length and width of the leaves in the 10 tufts selected were used in determining the leaf surface for a given section of the crown, and this in turn for finding the total leaf surface of a given tree. Table 16 shows that not only does the mistletoe shorten the length of both leaf tufts and leaves, but it also materially decreases the number of leaf tufts per tree for heavily infected trees when compared with healthy trees of the same age and site conditions. (Pl. V.) When two trees of the same size, one healthy and the other heavily mistletoed, are compared—Trees No. 103 and No. 107, for instance—it is seen that it has taken the mistletoe-infected tree more than twice the number of years to reach the same size as the healthy tree. The average ratio of the leaf surface in square feet to the total volume in cubic feet for the healthy trees given in Table 16 is 409.7 compared with 185.5 for the heavily infected trees.

Trees heavily infected with mistletoe not only have considerably shorter leaves and leaf tufts than healthy trees, but the leaves of mistletoe-infected trees are lighter in color than those of healthy trees, being a yellowish green as compared with the olive green on the healthy trees. Each heavy infection causes a localization and reduction of the photosynthetic or assimilatory leaf surface of the tree, which in turn results in a marked decrease in the rate of growth.

EFFECT ON LONGEVITY OF HOST.

A number of permanent sample plots were established on the Cocino and Tusayan National Forests by the Fort Valley Forest Experiment Station, in 1909, to determine the rate of growth and decadence, the rate of establishment of natural reproduction, and the effect of various factors upon regeneration on cut-over areas. These plots were remeasured in 1914 and 1919. Some of the plots yielded valuable data on the amount of mistletoe infection and the resulting mortality on cut-over areas.

On an area of 456 acres on the Tusayan National Forest about 5 miles from the Fort Valley Forest Experiment Station, 2,636 black jacks, or 34.9 per cent of the total number on the plot, and 225 yellow pines, or 34.8 per cent of the total number, were infected with mistletoe in 1914. In 1919, 2,335 black jacks, or 28.8 per cent of the total number of trees 4 inches in diameter and over, were infected with mistletoe. In many instances the infection was not sufficient to render the tree unhealthy, but with the increase of infection many of the infected trees will pass through the various infection classes and eventually die.

All of the trees which had died on the plots during the two 5-year periods were carefully examined and the cause of death noted. On the plot of 456 acres on the Tusayan National Forest 170 black jacks died from various causes during the first 5-year period, or 2.2 per cent of the total number of black jacks living on the plot in 1909, while 21 yellow pines died during the 5 years, which is 3.4 per cent of the total number of yellow pines living on the area. During the 5-year period from 1914 to 1919, 127 black jacks died from mistletoe alone, or in conjunction with other agents such as insects, porcupines, etc.

On a plot of 135 acres located on the Coconino National Forest about 1½ miles from the Fort Valley Forest Experiment Station, 27 black jacks died from various causes during the first 5 years, which is 1.1 per cent of the total number of black jacks living on the plot in 1909; 26 yellow pines, or 1.8 per cent of the total number, died during the same period.

A digest of that part of the detailed records pertaining to mistletoe as a cause of the death of western yellow pine during the 5-year period from 1909 to 1914 is given in Table 17. The 456-acre plot on the Tusayan National Forest is located on an area which has sustained heavy losses from mistletoe, while the 135-acre plot on the Coconino is located on an area with only occasional heavy infections. A study of Table 17 indicates the mortality of western yellow pine on these two areas and the extent to which mistletoe was a direct cause or a contributing factor. A study of Table 17 also indicates that of the 170 black jacks on the Tusayan plot which died during the 5-year period 26.4 per cent were killed directly by mistletoe, 42.3 per cent by mistletoe combined with other agents, and only 31.3 per cent died from other causes; while only 4.8 per cent of the yellow pines were killed by mistletoe combined with bark beetles. On the 135-acre Coconino plot mistletoe infection alone resulted in the death (Plate III, Fig. 2) of 7.5 per cent of the total number of dead black-jacks and 7.9 per cent of the total number of dead yellow pines, while mistletoe was a contributing factor toward the death of an additional 20.2 per cent of the yellow pines. During the 5 years 1.5 per cent

of the total number of black jacks on the Tusayan plot in 1909 were killed by mistletoe alone or in conjunction with other agents, mainly insects. While this figure itself is not high, it is alarming because the indications are that the death rate will increase from year to year, and although an effort was made to have all heavily infected trees removed when this area was marked for cutting, it is evident that mistletoe did not receive the attention which it deserved.

TABLE 17.—Classification of dead trees on permanent sample plots of 456 acres on the Tusayan and 135 acres on the Coconino National Forest.

Cause of death.	Per cent of dead trees, 1909-1914 (based on total number of trees which died during 5-year period).			
	456-acre plot, Tusayan National Forest.		135-acre plot, Coconino National Forest.	
	Black jack.	Yellow pine.	Black jack.	Yellow pine.
Mistletoe.....	Per cent. 26.4	Per cent.	Per cent. 7.5	Per cent. 7.9
Mistletoe and insects.....	35.0	4.8	.....	20.2
Mistletoe and porcupine.....	5.5	.....	.....	.....
Mistletoe and suppression.....	1.4	.....	.....	.....
Mistletoe, porcupine, and insects.....	.4	.....	.....	.....
All other causes.....	31.3	95.2	92.5	71.9
Total.....	100.0	100.0	100.0	100.0

Weir ⁴ has noted the same direct relation between mistletoe infection and insect infestation in the Northwest, especially with *Dendroctonus valens*. The origin of numerous insect infestations has been traced to stands of western yellow pine heavily infected with mistletoe.

The main difference between mistletoe and insect injury is in the length of time required for the injury to become manifest. A sporadic insect infestation may develop rapidly and may kill a large number of trees in a relatively short time, and it may even continue to increase until it is overcome and reduced to normal proportions through some natural agency. Mistletoe, on the other hand, develops slowly but continuously and persistently. The bark beetles, when attracted by the resinuous exudations of the mistletoe-infected trees, may materially hasten the death of the host which has already been weakened by the parasitic mistletoe. Trees dead or dying from mistletoe infection have been found infected with species of secondary bark beetles and borers, such as *Ips*, *Pityophthorus*, *Chrysobothris*, and *Melanophila*.

Three black-jack saplings under 4 inches in diameter breast high on one of the intensive mistletoe-study plots died during the five-year

⁴ Weir, James R., Mistletoe Injury to Conifers in the Northwest. U. S. Dept. Agri. Bulletin 360, 39 pp., 1916.

period as a direct result of mistletoe infection. Five yellow pines on the same area were also killed by mistletoe during the same period. Many of the other trees on the sample plots, although not dead at the last examination, were small and stunted; they were making an almost inappreciable growth and were very unhealthy in appearance. Some of these, which are apparently unable to endure the parasitism of the mistletoe combined with a rather adverse climate, will undoubtedly succumb before the remeasurement of the plots at the end of the next five-year period. Practically all of the trees which are heavily infected with mistletoe are ultimately doomed, since it is only a question of the length of time during which they can withstand the insidious action of the parasite.

EFFECT OF MISTLETOE ON MERCHANTABILITY OF TIMBER.

Although the mistletoe injury to the host results less in the depreciation of the lumber than in the impairment of the vital physiological functions of the tree, there is nevertheless an appreciable effect on the quality of the lumber. The accelerated growth of mistletoe-infected limbs, as shown in Tables 12 and 13, results in larger limbs which produce knots of a larger size in the lumber that is sawed from the boles of the mistletoe-infected trees. The number of knots is also increased by the greater number of secondary branches and twigs-in stem infections. The increased size and number of the knots may, in many cases, be sufficient to lower materially the grade of the lumber.

Mistletoe-infection produces a curly or abnormally grained wood and weaker lumber. Wood invaded by the thread-like sinkers of the mistletoe is spongy, and is frequently discolored and pitchy, as a result of the resinous flow or bleeding of the trees. The presence of mistletoe burls renders a tree more susceptible to wind breakage; in addition, it may ruin a portion or all of a sawlog. A seedling or sapling whose stem is infected with mistletoe will seldom develop a bole large enough to yield any considerable quantity of lumber and very rarely, if at all, lumber of a high grade. It is therefore evident that, aside from the physiologically injurious effect of the mistletoe, it also introduces a cull factor in that mistletoe-infected trees produce a poorer grade of lumber than healthy trees.

EFFECT OF MISTLETOE ON SEED PRODUCTION OF HOST.

Pearson⁵ has shown that, as a result of a collection in 1909, seed from mistletoe-infected black jacks gave a germination of 17 per cent below that of healthy black jack, which had a final germination of 78 per cent. The present study leads to the conclusion that,

⁵ Pearson, G. A. The Influence of Age and Condition of the Tree Upon Seed Production in Western Yellow Pine. U. S. Dept. of Agri., Forest Service Cir. 196, 1912.

although the mistletoe may stimulate growth in that portion of the host adjacent to the parasite, causing the abnormal development of certain limbs and branches into witches' brooms, the excess of carbohydrates produced by the additional foliage of the mistletoe-stimulated branches is consumed by the parasite, thereby reducing the amount available for the seeds. The effect upon the host in all cases is insidious, slowly depriving the tree of its vitality instead of causing injuries in the nature of a shock, as in the case of burns and other mechanical injuries. In this and the following study, no information was available as to the influence upon seed production of the condition of other trees which may have supplied the pollen for fertilizing the seed tree. Because of the lack of pollination experiments, the conclusions are necessarily based wholly upon the condition of the tree from which the seed was collected.

In order to check this theory further, additional seed collections were made by the Fort Valley Forest Experiment Station in 1913 and 1915 from mistletoe-infected and healthy western yellow pines. Aside from the difference in degree of mistletoe infection, the trees were otherwise normal and very similar in age and crown development. The seed extractions and germination tests were conducted separately for each tree. Five hundred seeds from each lot were germinated in sand in the greenhouse at a temperature ranging from 40° to 90° F., with a mean daily temperature of approximately 65° F. Daily counts were made during the progress of the germination tests, which continued for approximately 50 days.

The pertinent data on the seed production of 64 felled western yellow pine trees for the 1913 and 1915 collections are classified in Table 18, according to the degree of mistletoe infection. The best criterion by which to judge the relative seed production is believed to be the reproductive value of each tree or the total number of viable seeds produced per tree, which represents a convenient summation of the fundamental variables of seed production. This is obtained by multiplying the yield per tree in pounds of clean seed by the number of clean seeds per pound, and in turn multiplying the product by the final germination per cent. It will be noted that, with the exception of the lightly infected class upon which the mistletoe appears to have a slight stimulating effect, there is a decrease in the percentage of germination, the yield of cones, and clean seed per tree and consequently a marked decrease in the reproductive value per tree with an increase in the amount of mistletoe infection. The reproductive value of the trees in the intermediate infection class is about 40 per cent of that of the healthy class, while the reproductive value of the trees in the heavily infected class falls to only about 25 per cent of that of the healthy class. This is not surprising when the effects of the parasitism are fully understood. The data for the mistletoe-infected classes of

felled trees reported in Table 18 are meager because of the difficulty experienced in securing seed from mistletoe-infected trees, owing to the sterility of the cones and their failure to develop. In fact, a diligent search was made for heavily mistletoed trees which were bearing seed, but very few were found.

TABLE 18.—Data on the seed production of 64 felled western yellow pine trees classified according to degree of mistletoe infection.

Degree of infection.	Final germination.	Clean seeds per pound.	Yield per tree.		Reproductive value per tree.	Basis.
			Cones.	Clean seed.		
1913 collection:	<i>Per cent.</i>	<i>Number.</i>	<i>Bushels.</i>	<i>Pounds.</i>	<i>Number of viable seeds.</i>	<i>Number of trees.</i>
o.....	82.8	14,473	0.8	1.08	12,942	43
x.....	84.1	14,385	1.0	1.10	13,292	2
xx.....	81.7	13,314	.5	.45	4,895	2
xxx.....	77.0	14,475	.3	.31	3,455	2
Mean of x, xx, and xxx.	80.9	14,058	.6	.62	7,052	6
1915 collection:						
o.....	53.2	12,156	1.1	.83	5,626	11
Mean of x, xx, and xxx.	47.1	14,170	.9	.37	2,202	4

The extent and condition of the seed crop on the standing trees on the permanent sample plots were under observation from 1912 to 1916 in order to secure additional data on the effect of mistletoe infection on the amount and periodicity of seed production. The 1912 seed crop was rather light; only a few of the trees bore any large quantity of cones. In 1913 there was an average crop, with practically none in 1914, while the 1915 seed crop was somewhat below the average.

The records of the 1912 and 1915 seed crops for 90 of the living western yellow pines are classified in Table 19 by degree of mistletoe infection and amount of the seed crop. The seed crops were arbitrarily classified by the observer as heavy, good, medium, light, or none. An analysis of the data shows that the amount of seed production varies inversely with the degree of mistletoe infection. As the degree of mistletoe infection increases the amount of seed produced decreases until very little, if any, seed is produced by heavily infected trees.

These results are further substantiated by observations of the writers covering a period of approximately 10 years. Trees heavily infected with mistletoe produce small amounts of seed at such times as there are generally heavy seed crops, and at other times practically none. The few cones that may occasionally be found on trees heavily infected with mistletoe are very often aborted, and are frequently infested with a cone insect (*Conophthorus ponderosæ*).⁶

⁶ Material determined by Office of Forest Insect Investigations, Bureau of Entomology, U. S. Dept. of Agriculture.

TABLE 19.—*Record of 1912 and 1915 seed crops for 90 standing western yellow pine trees classified by degree of mistletoe infection and amount of seed crop.*

Degree of infection.	Amount of seed crop.										Total basis.
	Heavy.		Good.		Medium.		Light.		None.		
	Num-ber of trees.	Per cent.	Num-ber of trees.	Per cent.	Num-ber of trees.	Per cent.	Num-ber of trees.	Per cent.	Num-ber of trees.	Per cent.	Trees.
1912 seed crop:											
o.....	0	0	0	0	2	5.3	9	23.7	27	71.0	38
x.....	1	7.7	0	0	1	7.7	4	30.8	7	53.8	13
xx.....	0	0	0	0	0	0	5	25.0	15	75.0	20
xxx.....	0	0	0	0	0	0	0	0	16	100.0	16
1915 seed crop:											
o.....	0	0	1	2.8	2	5.5	15	41.7	18	50.0	36
x.....	0	0	0	0	2	14.3	5	35.7	7	50.0	14
xx.....	0	0	0	0	0	0	4	18.2	18	81.8	22
xxx.....	0	0	0	0	0	0	0	0	18	100.0	18

A similar deterrent effect of mistletoe on the seed production of Douglas fir, western larch, and lodgepole pine has also been found by Weir⁷ to obtain in the Northwest, where seed collected from very old mistletoe brooms showed a germination on an average of 10 per cent below that of seed taken from uninfected branches of the same trees. Munns⁸ reports that Jeffrey pine trees infected with mistletoe had half as many more seed to the pound as were found in the cones on thrifty trees, but the germination was 20 per cent lower and the seedlings produced were not so vigorous. It seems very improbable that moderate or heavy mistletoe infection would ever act as a stimulus upon seed production, because its slow, insidious action makes constantly greater demands upon the vitality of its host. Trees moderately or heavily infected with mistletoe are therefore of little or no value for the purpose of seed production.

The fact is fundamental in silviculture that variations in the individual characteristics of the parent trees are hereditarily transmitted through the seed.⁹ The extent to which the origin of the seed influences such characteristics as the resistance or immunity to disease, the rate of growth, and the growth-form of the regenerated forest, is of vital importance in the rational practice of scientific forestry.

The experiments of Zederbauer¹⁰ indicate that trees grown from seed collected from intermediate, suppressed, and weakened trees are less resistant to disease than trees grown from seed produced by dominant and vigorous trees. The hereditary characters of the species are not changed materially during one rotation. Several generations are necessary to show the true effects of those characteristics

⁷ Weir, James R. Mistletoe Injury to Conifers in the Northwest. U. S. Dept. of Agri. Bul. 360, 1916.

⁸ Munns, E. N. Effect of Fertilization on the Seed of Jeffrey Pine. Plant World, 22: 133-144, 1919.

⁹ Engler, Arnold. Einfluss der Provenienz des Samens auf die Eigenschaften der forstlichen Holzgewächse. Mitteilungen der Schweizerischen Centralanstalt für das forstliche Versuchswesen, Zürich, 1905, B. 8, s. 81-236; 1913, B. 10, s. 1-386.

¹⁰ Zederbauer, E. Centralblatt für das gesammte Forstwesen, 1912, s. 201.

of the parent tree which may be transmitted through the seed, such as an unusual divergence from the typical silvical characteristics of the species. A clearer conception of the latent possibilities of disease resistance and immunity of a species obtained through tree breeding is of vast importance in the silvicultural improvement and management of the forest. The hereditary influence of the parents upon the offspring is a well-recognized factor in genetics. This factor is doubly important in forestry, not only in the collection of seed for artificial regeneration, but also in the selection of seed trees to provide for the natural reproduction of cut-over forests. In timber-sale practice only thrifty seed trees should be left and all diseased and suppressed trees should be removed in order to improve the condition of the forests of the future.

SILVICULTURAL ASPECT OF MISTLETOE INFECTION.

The destruction caused by disease promises to approach or even surpass the losses from fire on the national forests of the Southwest, now that the development of fire protection has reduced the fire hazard. Mistletoe injury presents one of the most serious phases of this silvicultural problem. The parasite may be slow in effecting its injury, but it is unquestionably sure.

A brief discussion of some of the salient objects of silviculture is essential to a complete understanding of the significance of any methods of control which may be attempted. The chief fundamentals of silviculture, as applied in the regeneration of western yellow pine stands, are to maintain the continuity of the forest and to increase its productivity. A number of basic considerations must be taken into account under any rational method of cutting, among which may be mentioned the silvics of the species, the fire hazard and liability, exploitation and economic conditions, and the removal of the decadent, unhealthy, and overmature timber as rapidly as possible, to avoid waste through decay. All defective, diseased, and suppressed trees should be marked for cutting unless needed as fire insurance or seed trees. No defective or diseased tree should be left standing if it is evident that it will not live until the next cutting, unless it is absolutely required for silvicultural purposes. When it becomes necessary to reserve trees among the large diameter classes, thrifty, healthy trees of good form should be selected, since the condition of the progeny is influenced by heredity as well as by soil and climate. Increased forest productivity will be realized if, in the application of the above principles, the forester will also strive to eliminate the deterioration of merchantable material. It is thus evident that the marking on each individual area must be varied to meet the silvicultural requirements of the forest. The importance of careful, intelligent marking on timber-sale areas can not be over-

estimated, since this is the practicable means by which rational silvicultural management is actually secured.

Meinecke¹¹ has suggested the establishment of pathological rotations for species of economic importance which are subject to serious diseases. A pathological rotation may be defined as the period during which the timber crop may grow and be subject to exploitation at a profit, but beyond which rapid deterioration is imminent and the product will be marketed at a great reduction in value. The pathological rotation is therefore a limiting factor; and, with regard to heartwood-destroying fungi entering the heartwood through open wounds, it is based upon the age of decline or the age at which even unwounded trees become subject to heavy infection because they are unable to throw off the parasite or to hold its growth in check. From the discussion in the earlier part of this bulletin it will be seen that the mistletoe may kill small seedlings only a few years old, as well as veteran western yellow pines 200 to 300 years old. It is therefore evident that it would not be practicable to attempt to establish a pathological rotation for mistletoe-infected western yellow pine.

CONTROL OF MISTLETOE.

Any method of control of this serious and widely distributed enemy of the western yellow pine forests of the Southwest must be adapted to existing conditions. As in the case of other diseases, prevention is the basis for control. The protection of healthy stands of timber from disease is accomplished mainly by removing the source of infection.

Mistletoe is more susceptible to control measures than many fungi. Infection is confined to the aerial parts of the host, while fungi may infect the subterranean as well. The seeds of the mistletoe, which are much larger than the microscopic spores of fungi, are not subject to such wide dissemination. Mistletoe is killed with the death of its host, whereas certain fungi may remain alive for an indefinite period following the death of their hosts.

It is evident also that mistletoe develops rapidly after cutting, since many of the trees left standing on the permanent sample plots were killed by mistletoe during the five years following the logging operation; and many more, although still alive, will die in the course of a comparatively few years. In this study mistletoe was found to be directly or indirectly responsible for the greater number of deaths of western yellow pine.

All of the facts at hand indicate that the cutting of mistletoe-infected trees is the only practicable method of control. Since mistletoe appears to spread more rapidly and to grow faster on lightly infected trees, as a result of increased wind and light following

¹¹ Meinecke, E. P. Forest Pathology in Forest Regulation. U. S. Dept. of Agri. Bul. 275, p. 59, 1916.

cutting and providing more favorable conditions for the optimum development of the parasite, every effort should be made to free the stand entirely of mistletoe infection, although it is doubtful whether in certain cases the removal of lightly infected trees would be warranted because of silvicultural reasons. The increased activity of the mistletoe following the opening of the stand militates against leaving for a future cutting operation any but lightly infected trees, the infection of which is confined to the lower portion of the crown. Old and heavily infected trees should be cut for two reasons: (1) To improve the hygienic condition of the forests of the future through the removal of the mistletoe, and (2) to secure the maximum realization on a rapidly diminishing growing stock or forest capital. Since the future productivity of the forests depends to a great extent upon the proper choice of seed trees or of the seed itself in the case of artificial regeneration, those trees used for reproductive purposes should be sound, healthy, and of an intermediate age class.

As heavy a stand of healthy trees as possible should be left in order to compensate for the removal of diseased trees, and to maintain better forest conditions, reduce wind damage, and insure a denser stand of reproduction. Exceptional care should be taken to leave every healthy black jack which is free from infection. Wherever possible, trees should be freed from light infections by cutting off lower branches within reach. Transition trees and vigorous yellow pines, suitable for seed trees, should be left in greater numbers to take the place of diseased black jacks removed, to maintain better forest conditions, and to furnish abundant seed for the restoration of the stand. Small heavily infected black jacks should be marked wherever it is possible to have them cut under the sanitation clause of the timber-sale contract, or where there is a market for small material, such as stulls, mine props, ties, poles, posts, and pickets.

Forest officers in charge of marking on mistletoe-infected timber-sale areas should study carefully the possibilities of increasing the number of healthy trees in the remaining stand. The pruning of infected limbs from small trees at the time of marking presents a practical means of eliminating light limb infections and at the same time increasing the number of healthy trees. Occasionally there are trees in a stand that are lightly infected on a low branch within reach of the ground. Mistletoe-infected reproduction and young timber below merchantable size should also be freed from the disease either through cutting the seedlings and saplings or by lopping off the infected branches. Such measures may be impracticable except on timber sale areas and in some cases the extra labor and expense involved may prove prohibitive.

The areas of mistletoe infection should be located and mapped as a prerequisite to an efficient control campaign. The degree of injury

and the amount of infection should also be recorded. Weir¹³ has suggested that this could easily be done by timber-survey parties in connection with their regular mapping and cruising work. Such tangible records of mistletoe infections would be invaluable to forest officers in showing just where diseased stands are located, in order that an attempt be made to exploit stands of seriously diseased timber as rapidly as possible.

The advent of a large commercial timber-sale operation should not be awaited before undertaking mistletoe-control work. Small ranger sales and even the issuance of free-use permits would materially assist in the reduction of severe infections. Although in many instances the large lumbering operation is more economical than the small one, the latter can render a definite service in improving the hygienic condition of the forest through removing more or less isolated infections which are too small to be exploited in a large operation. The products of the small operation are not marketed in such highly finished or specialized form as are many of the products of the large operation. In the case of a small lumbering operation mistletoe-infected trees will, in almost every case, be as well adapted to the desired uses as the products of healthy trees.

The problem of the control of mistletoe assumes two quite different aspects, depending upon the degree of infection on a given area. Silvicultural systems of regeneration should provide for the eradication of the mistletoe from the stand as one of the most necessary results to be accomplished. On areas adequately stocked with advance reproduction all infected trees should be cut. On the other hand, on areas of light to moderate infection special emphasis should be laid upon the need of leaving all healthy trees possible, even if they belong to the "yellow-pine" class, in order to insure as good a condition of the forest cover and seed production as possible. Where the injury is not very serious the marking rules should call for the removal of all mistletoe-infected trees possible without breaking up the continuity of the stand or materially interfering with the silvicultural system of management adopted for the area. Lightly infected areas should be marked in such a manner that, with supplemental pruning at the time of marking, the stand would be practically free of infection. Lightly infected black jacks and transition trees on areas bearing no advance reproduction should not be cut when otherwise thrifty and sound, except where thinnings are desirable to obtain increased growth or where reproduction is established. Such thinnings, however, may be somewhat heavier than in uninfected stands; but in lightly infected black-jack stands where reproduction is not established vigorously growing and thrifty trees should not be radically sacrificed.

¹³ Weir, James R. Some Suggestions on the Control of Mistletoe in the National Forests of the Northwest. *Forestry Quarterly*, 14: 567-577, 1916.

Lightly infected yellow pines should be left when uninfected trees or lightly infected black jacks are not available for seed and protection.

Moderately infected trees should always be marked for cutting, except where there are no other trees available to leave as seed trees. Mistletoe can not in all cases be eliminated in one cutting without too great a sacrifice of silvicultural requirements. Moderately infected trees should not be left for seed on lightly infected areas if healthy trees are available within 100 yards. This, however, applies to large areas rather than to small openings or small areas which have a chance to seed in from surrounding trees and where infection might be removed completely without opening the forest too extensively. Moderately infected trees should be left for soil-protection purposes only on the most adverse sites, where their need for this purpose is clearly evident.

Areas of heavy infection on which the injury from mistletoe is alarming should receive special attention and should be treated from the standpoint of the sanitation of the forest. Areas where the entire stand is too heavily infected to permit carrying out sanitation measures without material interference with the silvicultural requirements of the forest should be marked for clear cutting. In practice such a condition will seldom be encountered. The largest possible number of small trees infected with mistletoe should be utilized. Areas of unmerchantable reproduction infected with mistletoe should be freed of the disease either through cutting the diseased seedlings and saplings or by pruning off infected branches. In certain cases it would be desirable for the owner of the forest to devote special funds for mistletoe-control projects, as is done in the case of serious insect infestations.

While the areas infected with mistletoe to such an extent that diseased trees must be left or the stand practically clear cut, are not extensive, areas will probably be found on which forest planting to fill in blank growing spaces will be desirable following operations approaching a clear cutting under a mistletoe-control project. It may also be advisable from the standpoint of economy to clear-cut and plant certain limited areas of heavy infection. A definite policy of mistletoe control should be adopted for mistletoe-infected areas to be cut over by timber sales. Necessary funds should be provided to complete the cleaning of the areas after the operator has removed all of the diseased trees which he can be required to take under the agreement.

Forests in the vicinity of nurseries and planting areas should present unusually healthy conditions. It should be remembered that healthy trees can not be grown in an insanitary environment. All mistletoe infection in the vicinity of forest nurseries and planting areas should therefore be removed.

When a proposed timber-sale area contains a considerable amount of mistletoe, a special mistletoe sanitation clause should be inserted in the contract, containing the stipulation that all heavily infected trees, whether merchantable or unmerchantable, and certain other moderately infected trees will be marked for cutting. If the amount of unmerchantable infected timber is sufficient to affect the stumpage price materially, this factor should be fully taken into consideration and due allowance made for it in the stumpage appraisal.

In control work on those areas where both mistletoe and insects are present, it would be advisable to combine the eradication of both pests where the commercial value of the stand justifies such measures. Infestations of secondary bark borers have occasionally been found and reported with or immediately following mistletoe infection.¹⁴ It is believed that certain of these insects even show a slight preference for trees infected with mistletoe. The attack of trees weakened by the mistletoe often hastens their death, or in the case of dead trees the work of the borers hastens deterioration. The control of such combined infection and infestations by eliminating the weakened trees would tend to control both mistletoe and insects, and thus hasten the realization of the ideal—a productive, thrifty, and healthy forest.

The western yellow pine mistletoe probably has few natural enemies which can contribute toward its control. During the course of the studies reported in the preceding pages, a spittle insect (*Clastoptera obtusa*)¹⁵ was very frequently found within masses of spittle on the mistletoe plants. The work of the insect in controlling the mistletoe is probably of little practical importance. However, since the insect subsists on the juices of the mistletoe, it must tend to weaken the mistletoe to a certain extent, especially in cases of severe infestations.

Through a proper realization and appreciation of the necessity for adequate control measures and their adoption on all cutting areas where the amount of mistletoe infection is relatively great, a very good beginning can be made toward the eradication of the pest through the more or less gradual process of elimination.

SUMMARY.

Western yellow pine is subject to severe injury by mistletoe (*Razoumofskyia cryptopoda*). The injury to the forest caused by the insidious and destructive action of this pest results in serious losses of western yellow pine and presents one of the most important silvicultural problems in the Southwest.

¹⁴ Hopping, Ralph. Insect Infestation in Relation to Injury, Fungi, and Mistletoe. Manuscript report. February 24, 1915.

¹⁵ Determined by E. H. Gibson, Scientific Assistant, Bureau of Entomology, U. S. Department of Agriculture.

Mistletoe infection causes a marked decrease in the rate of growth of the host, which continues until the virulent parasite ultimately causes the death of the tree. The rate of decrease varies directly with the degree of infection from little or no decrease in the growth of lightly infected trees to a very marked falling off in the current growth of heavily infected trees. Many trees are killed annually by this pest alone or in conjunction with other causes, such as insect infestations or porcupine injury.

The decrease in the rate of diameter and height growth and the consequent current increment of trees infected with mistletoe are accompanied by a reduction of the leaf surface of the host.

Trees of all age classes are subject to mistletoe infection, provided the seeds of the parasite fall on parts of the tree which are not protected by the bark. Young seedlings and saplings usually die comparatively soon after becoming severely infected, while older trees may remain alive for a much longer time.

The quantity and quality of the seed produced by trees infected with mistletoe is below that of normal, healthy trees. Heavily infected trees are practically worthless for seed production and should not be left as seed trees.

The most practical method of controlling mistletoe is to remove the infected trees while cutting operations are in progress. All heavily infected trees should be marked for cutting. Moderately infected trees should be marked for cutting except where others are not available for seed trees. On areas of light to moderate infection the marking rules should require the removal of all mistletoe-infected trees possible without breaking up the continuity of the stand or materially interfering with the silvicultural requirements of the forest. Exceptional care should be taken to leave as heavy a stand of healthy trees as possible in order to compensate for the removal of diseased trees and to maintain better forest conditions.

Areas on which the entire stand is too heavily infected with mistletoe to permit adequate sanitation measures without very material interference with the silvicultural requirements of the forest should be marked for clear cutting under a mistletoe-control project. Although in actual practice such a condition will seldom be encountered, relatively small areas will probably be found on which forest planting may be desirable.

When proposed timber-sale areas contain a great amount of mistletoe, a sanitation clause should be inserted in the timber-sale contract requiring the cutting of all heavily infected trees, whether merchantable or unmerchantable, and certain other moderately infected trees which may be marked.

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DECAYS AND DISCOLORATIONS IN AIRPLANE WOODS.

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INTRODUCTION.

The purpose of this bulletin is to enumerate and describe the more important decays and discolorations to which woods used in aircraft construction are subject and the conditions under which they occur. It is well known that the initial or incipient stages of decay—that is, the first steps in weakening wood—are indicated by discolorations, but wood is subject to many color variations from the normal not caused by wood-destroying fungi.

The value of recognizing the true nature of any given discoloration or other abnormality is immediately apparent, since such knowledge will permit the free use of wood which, though seriously reduced in value from an æsthetic standpoint by a disagreeable discoloration, is not mechanically weakened, while at the same time dangerous color variations can be detected. In the airplane industry, where the very finest quality of high-grade wood is demanded, and in which there is a maximum of unavoidable waste in the remanufacture of the lumber, it is imperative that no suitable material be wasted or diverted to another purpose, while at the same time it is equally important that all weakened material be excluded.

This bulletin first considers certain defects in airplane woods not due to decay, but which must be readily recognized in order to avoid

confusion. Next are described the various discolorations in airplane woods caused by mechanical injuries to the living trees, chemical reactions, harmless fungi, and decay-inducing fungi in relation to their actual effect on the strength of wood. In the case of those defects and properties which it is not within the province of this bulletin to discuss in detail, references to available literature are given.

GENERAL CONSIDERATIONS.

There are certain basic principles in the manufacture of high-grade lumber which should be most rigidly adhered to in the case of stock for airplanes. The purchaser should be certain that the manufacturer supplying his requirements is both willing and able to fulfill these conditions, so that defects very difficult to detect are not introduced.

When trees are felled the logs should be removed from the woods with reasonable promptness, because as soon as the timber is down it becomes subject to decay, sap-stain, checking, and the attacks of wood-boring insects. Leaving logs in the woods over winter is particularly poor practice. If the logs must be stored for any considerable length of time they should be kept in the pond, where the defects mentioned will be largely prevented.

After the logs are sawed the lumber should be carefully inspected and those pieces unsuitable for use in airplanes diverted to other uses. Next comes seasoning. Drying with artificial heat in dry kilns is preferable. The kilns should be of proper construction, so that the temperature and relative humidity can be completely controlled and the lumber brought to an average final moisture content of about 8 per cent, within the limits of 5 to 10 per cent (based on oven-dry weight), without checking or other injury. If it is necessary to store the dry lumber at the mill it should be placed in a dry shed, completely protected from the weather. The shed should have a board floor. Concrete, particularly if new, or dirt floors may give off considerable moisture. The stock should be shipped in box cars completely protected from moisture. When it reaches the factory the lumber should be shop seasoned; that is, placed in a room under uniform shop conditions, for about two weeks. During the entire process of manufacture the stock should be carefully protected from the absorption of moisture. Piling lumber or partly fabricated parts on damp floors or under the drip from steam or water pipes are two not uncommon offenses.

In case it is impossible to kiln-dry the stock, air drying must be resorted to. As a rule it is not possible to get the moisture content below 11 per cent by this process, except in arid regions. When the lumber comes from the saw it may be necessary to dip it in a chemical solution to prevent sap-stain in regions where lumber is especially subject to this discoloration; but under any conditions the stock should be carefully open-piled on elevated foundations to assure a circulation of air throughout and only sound, bright, thoroughly seasoned stickers used between courses. The piles should be properly slanted and roofed, so that rain will run off and not soak the lumber. To pile lumber closely, without proper circulation of air throughout the piles, results in some cases in warping, sap-stain,

and, ultimately, decay. Then, too, it is almost impossible for the stock in the center of the pile ever to become properly dry.

At best, however, air drying is a matter of months, even with softwoods, while proper kiln drying can be accomplished within one to three weeks or so, depending on the thickness of the stock. As a rule, hardwoods both kiln-dry and air-dry more slowly.

Air-dried stock should be shipped in the same manner as kiln-dried and handled in the same way at the factory, except that it must be kiln-dried to the proper moisture content before it is conditioned in the shop.

The principles given briefly in the foregoing paragraphs, together with their application and underlying reasons, are brought out in detail in the following pages.

WOODS USED FOR AIRPLANE CONSTRUCTION.

The most important wood for aircraft construction is spruce, including red, white, and Sitka spruce (*Picea rubens* Sarg., *P. canadensis* (Mill.) B. S. P., and *P. sitchensis* (Bong.) Trautv. and Mayer), but of these Sitka spruce, on account of its much larger size and the consequently greater quantity of clear lumber that can be obtained, is paramount. By far the greatest proportion of the lumber entering into the construction of most present-day airplanes is spruce or one of its substitutes. The combination of strength properties with light weight found in spruce is not duplicated in any other wood. Most of the beams in the directing surfaces are preferably of spruce or a soft wood, as are many of the struts, and these parts account for the bulk of the timber in an airplane.

An excellent substitute for spruce is Port Orford cedar (*Chamaecyparis lawsoniana* (Murr.) Parl.), which is slightly heavier. Unfortunately the supply of this splendid wood is decidedly limited. Douglas fir (*Pseudotsuga taxifolia* (Lam.) Br.), though much heavier than spruce, is an extensively used substitute. Other woods which can play some part in this way or may be used for special purposes where a softwood is needed are western white pine (*Pinus monticola* Dougl.), sugar pine (*P. lambertiana* Dougl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), white fir (*Abies concolor* (Gord.) Parry), amabilis fir (*A. amabilis* (Loud.) Forbes), noble fir (*A. nobilis* Lindl.), yellow or tulip poplar (*Liriodendron tulipifera* Linn.), basswood (*Tilia americana* Linn.), incense cedar (*Libocedrus decurrens* Torr.), and western red cedar (*Thuja plicata* Don.). Certain parts of an airplane frame as a rule are made from hardwoods. In such parts great strength and toughness are requisite. Here, commercial white ash¹ stands supreme. For example, it is unsurpassed for longerons in those fuselages not constructed wholly or mostly of veneer. Black ash (*Fraxinus nigra* Marsh), which does not possess sufficient stiffness for use in highly stressed parts, can be distinguished from white ash (2; 30, p. 47; 68, p. 62).² White oak,³ hard maple (*Acer saccharum* Marsh), and

¹ Commercial white ash includes white ash (*Fraxinus americana* Linn.), green ash (*F. lanceolata* Borkh.), blue ash (*F. quadrangulata* Michx.), and Biltmore ash (*F. biltmoreana* Beadle).

² Serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

³ White oak as used here includes white oak (*Quercus alba* Linn.), bur oak (*Q. macrocarpa* Michx.), cow oak (*Q. michauxii* Nutt.), and post oak (*Q. minor* (Marsh) Sarg.).

rock elm⁴ are sometimes used instead of white ash. Hickory,⁵ so far, has been principally used for tail skids. The two finest woods for propellers are black walnut (*Juglans nigra* Linn.) and true mahogany (*Swietenia mahagoni* Jacq.), also known as Central American mahogany. Other species commonly used are yellow birch (*Betula lutea* Michx. f.), sweet birch (*B. lenta* Linn.), African mahogany (*Khaya senegalensis* A. Juss.), black cherry (*Prunus serotina* Ehrh.), hard maple, white oak, and yellow poplar. However, a number of other woods are occasionally utilized, and in the future a wide variety of species will probably be admitted. European designers even now are less exacting in this respect, sometimes using two species of wood in the same propeller, which on the whole is considered poor practice in this country.

TABLE 1.—Distribution of wood in airplanes, showing the service requirements and the adaptation thereto of the different grades of the several species.

Designation of assembly and name of part.	Species of wood and quality designation (grade).												
	Spruce.	Douglas fir.	Port Orford cedar.	Basswood.	Tulip poplar.	White pine.	White fir.	Western hemlock.	White ash.	White oak.	Hard maple.	Rock elm.	Hickory.
Main and center planes, ailerons, stabilizer, elevator, rudder, and fins:													
Beams, solid.....	A	A	A	.....	A	A	A	A	.....	.....	.....	.....	.....
Beams, box.....	A	A	A	.....	A	A	A	A	.....	.....	.....	.....	.....
Filler blocks.....	C	C	C	C	C	C	C	C	.....	.....	.....	.....	.....
Fillet strips.....	B	B	B	B	B	B	B	B	.....	.....	.....	.....	.....
Panel blocks—													
Brace blocks.....	C	C	C	C	C	C	C	C	C	C	C	C	C
Corner blocks.....													
Spacer blocks.....													
Reinforcing blocks.....													
Rib webs, solid.....	B	B	B	B	B	B	B	B	.....	.....	.....	.....	.....
Rib webs, compression (solid).....	A	A	A	A	A	A	A	A	.....	.....	.....	.....	.....
Compression struts.....	A	A	A	.....	A	A	A	A	.....	.....	.....	.....	.....
Cap strips.....	A	A	A	A	A	A	.....	.....	.....	.....	.....	.....	.....
Trailing edge—													
Straight.....	B	B	B	.....	B	B	B	B	.....	.....	.....	.....	.....
Bent.....	.....	.....	.....	.....	.....	.....	.....	.....	A	A	A	A	A
Entering edge—													
Straight.....	B	B	B	.....	B	B	B	B	.....	.....	.....	.....	.....
Bent.....	.....	.....	.....	.....	.....	.....	.....	.....	A	A	A	A	A
Gussets.....	B	B	B	.....	B	B	.....	.....	.....	.....	.....	.....	.....
Masts.....	A	A	A	A	A	A	.....	.....	.....	.....	.....	.....	.....
Stringers.....	B	B	B	.....	B	B	B	B	.....	.....	.....	.....	.....
Interplane struts.....	A	A	A	.....	.....	.....	.....	.....	A	A	A	.....	.....
Center section struts.....	A	A	A	.....	.....	.....	.....	.....	A	A	A	.....	.....
Fuselage:													
Longerons—													
Straight.....	A	A	A	.....	.....	.....	.....	.....	A	A	A	A	A
Bent.....	.....	.....	.....	.....	.....	.....	.....	.....	A	A	A	A	A
Struts, vertical, and horizontal—													
High stress.....	A	B	A	.....	A	A	A	B	B	B	B	B	B
Low stress.....	B	B	B	.....	B	B	B	B	.....	.....	.....	.....	.....
Struts, diagonal.....	B	A	B	.....	B	B	B	B	A	.....	.....	.....	.....
Supports, heavy.....	A	A	A	.....	A	A	A	A	.....	A	A	.....	.....
Supports, light.....	B	B	A	B	B	B	B	B	B	.....	.....	.....	.....
Brace blocks.....	B	B	B	B	B	B	B	B	.....	B	B	B	.....
Stiffeners.....	B	B	B	B	B	B	.....	.....	.....	.....	.....	.....	.....
Cleats.....	.....	.....	.....	.....	.....	.....	.....	.....	C	C	C	C	.....
Furring strips.....	B	B	B	B	B	B	B	B	.....	.....	.....	.....	.....
Floor and seat boards.....	C	C	C	C	C	C	C	C	.....	.....	.....	.....	.....
Cradle slats.....	C	C	C	C	C	C	.....	.....	.....	.....	.....	.....	.....
Seat rail.....	A	A	A	A	A	A	A	A	.....	.....	.....	.....	.....
Tail post.....	A	A	A	.....	.....	.....	.....	.....	A	A	A	A	.....
Tail skid.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Landing chassis:													
Struts.....	A	A	A	.....	.....	.....	.....	.....	A	A	A	A	A
Stream lining.....	C	C	C	C	C	C	C	C	.....	.....	.....	.....	.....

⁴ Rock elm includes rock elm (*Ulmus racemosa* Thomas) and the more dense stock of both white elm (*U. americana* Linn.) and slippery elm (*U. pubescens* Walt.).

⁵ The true hickories include mockernut hickory (*Hicoria alba* (Linn.) Br.), shellbark hickory (*H. laevis* (Michx. f.) Sarg.), pignut hickory (*H. glabra* (Mill.) Br.), and shagbark hickory (*H. ovata* (Mill.) Br.).

Table 1, which is an adaptation of specification 15037-B of the Bureau of Aircraft Production, shows where the various woods may be used in an airplane and the quality desired. The symbol *A* indicates a grade of wood of the very highest quality and free from all injurious defects; grade *B* demands a quality of wood similar to grade *A* in all respects except that a little tolerance is allowed in regard to straightness of grain and specific gravity; wood of grade *C* is used in parts where little strength is needed and may contain various defects, provided the piece is strong enough for the purpose intended.

These woods are not the only ones used for airplanes, but they are the most important. Others are mentioned here and there in this bulletin. It can be predicted that, with a growing scarcity of the more desirable species and an increase in our knowledge of the properties of other species, woods little or not at all used at present will become of importance. For a full discussion of this entire subject, the reader is referred to other sources (60; 69, p. 34-40).

GENERAL DEFECTS OF AIRPLANE WOODS.

It is impossible to thoroughly understand wood without a working knowledge of its structure and mechanical properties. This is more difficult to attain than with most other materials of construction, for wood, instead of being a relatively simple and more or less homogeneous compound, is a highly complex organic structure whose chemical composition is even now none too well understood. The discussion in the following pages will be much clearer to the reader provided he has such knowledge. There are a number of valuable publications which may be referred to in this connection (30, 45, 47, 48, 68, 69).

Besides decay, there are other defects which reduce the strength of timber, and these must be given due consideration. Wood may be inherently weak because of its structure, it may be injured by some process of manufacture, or the trouble may be due to faulty design or assembly. Such defects in relation to airplane woods have been discussed in various publications (42; 46; 68, p. 15-20; 69, p. 11-22), but a review of the more important of these is essential here, since by the uninitiated some of them are confused with decay.

GRAIN.

One of the most common defects in airplane woods is an excessive slope of diagonal or spiral grain. Since any deviation from straight grain is accompanied by a reduction in strength, the requirements in this respect are very exacting, a deviation from straight grain of more than 1 inch in 20 inches rarely being allowed for any highly stressed portion of an airplane, although this may be reduced to 1 inch in 12 in portions of less severe stress. A discussion of the methods to be employed in detecting this defect, together with its effect on strength, may be found in several publications (31; 42, p. 8-14; 68, p. 15-16; 69, p. 11-20).

SPECIFIC GRAVITY.

Brashness or brittleness in wood is another common defect. These synonymous terms denote a lack of toughness in wood to which they are applied. Brash wood is usually low in strength, and when

tested by bending fails with a short break instead of a splintering fracture. This is one indication of decay, but not all wood showing such defect is decayed. Too often when wood appears to be somewhat brash and develops less than the normal strength, instead of making a serious attempt to determine the real source of the difficulty the cabalistic term "dry-rot" is uttered, and the case is settled, often resulting in the loss of good material, while the trouble goes on unchecked. Even if the wood be decayed, it most probably is not dry-rot, which term to the pathologist embraces a definite type of decay caused by a certain fungus. Let us consider a few of the more important causes of brashness, aside from decay, in aircraft woods.

The primary requisite of wood for use in airplanes is that it must be of specific gravity high enough to give the necessary strength. It has long been known that an increase in strength of any species of wood goes with an increase in specific gravity, and it has finally become possible accurately to express this relation for the various strength properties, so that if the specific gravity of a given piece of wood is known it is possible quite accurately to derive its strength under various stresses (41). No matter how perfect a piece may be in other respects and free from all other defects, if it is below the minimum specific gravity it should not be used. These minimum figures have been carefully worked out for the more important airplane woods (68, p. 21; 69, p. 26). Wood of low specific gravity is naturally somewhat brittle, and for this reason is often erroneously considered as slightly decayed. While the actual specific gravity of the wood substance in various species is practically the same (13), having a value of 1.54, the porous nature of the wood is such that most commercial species range from 0.3 to 0.6. In other words, only one-fifth to three-fifths of a unit volume of wood is occupied by wood substance; the remainder is air.

It is self-evident that a density or specific gravity determination of every individual piece of wood to be used for a primary member in an airplane is out of the question. Neither is it necessary. The most reliable index of specific gravity, without making an actual test, is the ratio of spring wood to summer wood per annual ring. This is best seen on the cross or end section after it has been smoothed off with a sharp knife or a high-speed miter saw. In the softwoods the summer wood is the darker of the two bands composing each annual ring, as is shown in Figure 1, which illustrates cross sections from two wing beams of Douglas fir, one of average and the other of low specific gravity. In the ring-porous hardwoods (ash, for example) the summer wood appears more solid and very much less porous than the spring wood, but in the diffuse-porous hardwoods (such as birch) this is often very difficult to determine. For Douglas fir a minimum specific gravity of 0.47 has been established for high-stressed members, but this can probably be reduced to 0.45 with perfect safety when used as a substitute for spruce. As a rule, wood of this species with less than 6 or more than 30 annual rings per inch, measured radially on the cross section, falls below the minimum specific gravity. The former usually comes from the center of the tree, where the wood is rapid growing and brash, while the latter is the slow-grown soft "yellow fir" so characteristic of the outer layers

of very old trees. If each annual ring is composed of approximately one-third or more of summer wood the piece possesses the necessary strength. In those pieces with very narrow annual rings, in which the summer wood is indicated by a mere dark line at the outer edge of each annual ring, the wood is very soft and weak, often having a specific gravity as low as 0.34 (Fig. 1).

Sometimes the proportion of material of low specific gravity in Douglas fir airplane lumber is exceedingly high. The writer has seen several consecutive carload lots of selected wing-beam stock at one factory in which from 25 to 50 per cent of the pieces in each car were below the minimum specific gravity. The stock was cut from old

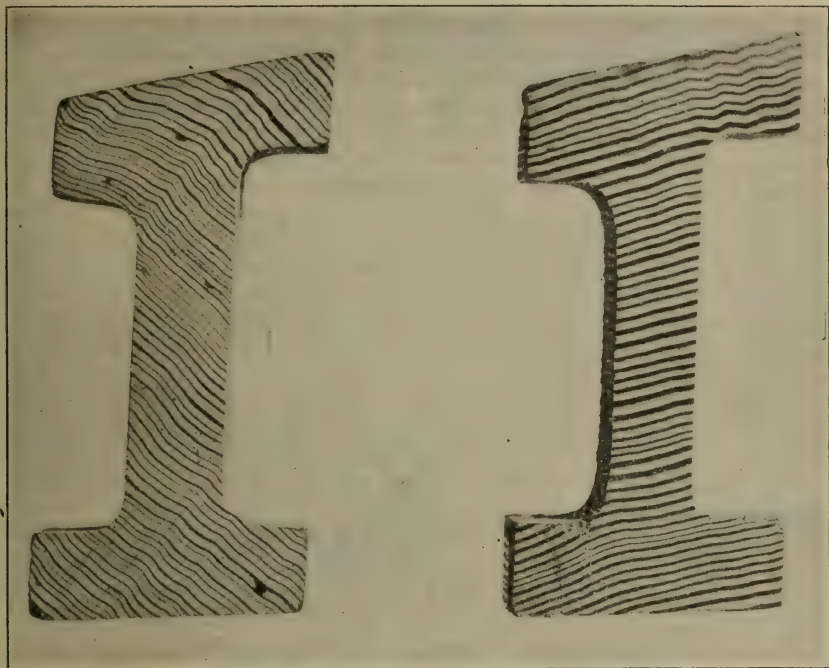


FIG. 1.—Cross sections of wing beams of Douglas fir of average and low specific gravity. The large proportion of summer wood, indicated by the dark bands, in the piece of good specific gravity (on the right) in comparison with that in the piece with low specific gravity (on the left) is plainly shown.

slow-grown trees, which yield the "yellow fir" so much preferred by the trade, but which invariably contain a large percentage of material of low specific gravity not suitable for aircraft or any other type of construction where high strength is requisite.

The same general relations hold good in Sitka spruce. Here, again, if the annual rings are too few or too many per inch, they indicate wood of low density. The minimum specific gravity for this species is established at 0.36.

It is often difficult to approximate the specific gravity by visual examination of the proportion of summer wood per annual ring in the case of those pieces close to the minimum density permitted in softwoods. There is considerable chance for error even with Douglas fir, but with spruce this is increased, owing to the fact

that the summer wood and spring wood merge into each other, not being sharply delimited as in Douglas fir. With experience it is quite feasible to judge with accuracy the relative specific gravity of many of the pieces, leaving the doubtful ones for an actual test or to be worked up along with those below the minimum into parts less highly stressed. In making tests to determine the specific gravity it is not necessary to use the time-consuming immersion method. The pieces can be cut fairly regularly, oven dried, and the volume ascertained by measuring to the nearest half millimeter or to the nearest sixty-fourth of an inch. The weight should be obtained as usual. The writer has tested this method extensively and found the limit of error rarely over 0.01. In most cases the result will not vary from that obtained by the immersion method. This method can not be used on irregularly shaped pieces, however.

In the ring-porous hardwoods, such as ash, it is very easy to determine the relative proportions of spring and summer wood in each annual ring. Here the condition is the reverse of that found in the softwoods. About three-fifths or more summer wood per annual ring in the case of white ash is necessary to give the strength required by the minimum specific gravity of 0.56. Wood with few annual rings to the inch in white ash has a high specific gravity, and this, as a rule, decreases as the number of rings per inch increases. Wood with 20 to 25 annual rings or more to the inch is usually worthless if strength is a requisite. The relations just discussed are fairly constant throughout the ring-porous hardwoods, such as white oak, rock elm, and hickory.

A large proportion of summer wood is not always an indication of strength in white ash. The notable exception to this rule is pumpkin ash, so called by the trade. This ash has remarkably broad bands of summer wood in the annual rings. These rings are often half an inch broad and contain only one or two narrow lines of pores in the spring wood, but the specific gravity of the wood is low, and when tested in static or impact bending it breaks with a brash, brittle failure under a light load. It can readily be detected by cutting with a knife, yielding softly without the resistance offered by good ash. When finished it has a waxy white, cream, or light-brown color in tangential section and can be readily dented with any hard blunt instrument. In cross section the pores in the summer wood sometimes appear as small brown, rather indistinct spots.

Pieces may be found with almost the same appearance as pumpkin ash which when tested with a knife prove to be hard and tough, with a good specific gravity; or, again, both hard and soft wood may be found in the same board.

As nearly as can be ascertained from hearsay evidence, this pumpkin ash is not confined to a particular tree species, but may be found in any of the white-ash group when grown under swampy conditions in the southern part of the range. It does not necessarily occur, but when it does the central portion of the butt logs or even the entire trunk may be composed of such wood. Pumpkin ash has been assigned by botanists as the common name for one definite tree species (*Fraxinus profunda* Bush), but the name as applied in the lumber trade denotes white-ash wood having the characteristics above described without regard to species.

It is quite difficult to judge the specific gravity of diffuse porous hardwoods by visual examination except in those pieces patently very low or very high. Actual specific-gravity determinations will have to be used to a greater extent when handling this class of woods.

In examining a piece of wood of any considerable length to determine its specific gravity, care must be used to examine it throughout. Pieces in which the grain is not perfectly straight may have high specific gravity in one portion and a low density in another, as attested by the percentage of summer wood. This is due to the fact that trees may not develop wood of the same or nearly the same specific gravity throughout their life. Such a condition is not at all uncommon in white-ash longerons, and it must be remembered that any given piece of wood is no stronger than its weakest portion.

As a general rule, airplane timber should be purchased under specifications so worded in regard to the ratio of spring wood and summer wood per annual ring and number of annual rings per inch of radius as to reject at the source of supply most of the stock of low specific gravity.

COMPRESSION WOOD.

Occasional pieces of wood of unusual growth are encountered. The annual rings are very broad, with an abnormally large proportion of summer wood per annual ring, and there is little contrast between the spring wood and the summer wood. The specific gravity is very much higher than that of normal material. The abnormal growth is supposed to be due to the fact that the tree or portion of the tree from which the piece came had been under some long-continued unusual stress or had been in an unusual position. The term "compression wood" is usually applied to material of this nature. The writer remembers particularly a spruce wing beam with six annual rings per inch of radius, 75 per cent or more of summer wood per annual ring, and a specific gravity of 0.85. Since the usual specific gravity of spruce used is about 0.40, it can readily be seen that the weight of this wing beam was more than double the normal. Compression wood is not confined to spruce, but may be found in other soft woods. This type of wood is not desirable. Its strength properties are uncertain, and its shrinkage does not correspond to that of normal wood, the longitudinal shrinkage being several times as great, while the radial and tangential shrinkage is very much less. The excessive weight is also a factor that must be considered in a delicately balanced machine.

STEAMING AND BENDING.

Wood may be rendered brittle or otherwise injured by steam bending if this is not properly done. It is necessary to bend certain parts of an airplane frame in this way in order to obviate the initial stresses which would result if these members were simply sprung into place. This should not be attempted on thoroughly air-dry or kiln-dry material, because wood once dried is weaker when brought back to a higher moisture content, and in addition such material has a tendency to spring back after the clamps are removed if it was not thoroughly resoaked. As a rule, wood with less than 18 per cent of moisture based on oven-dry weight should not be steamed and bent.

Too high temperatures in the steam box will make wood brittle, seriously weakening it. Steaming should be accomplished at atmospheric pressure and for a period not to exceed six hours. Higher pressure means higher temperatures and weakened wood. Most hardwoods are more or less discolored by this process, assuming a dead-gray color, but this does not indicate injury. White oak may change to a blackish brown. White ash becomes a dead-gray color, on which a bluish gray discoloration may appear. Elm also takes on this gray shade to some extent. The change in color is very much less noticeable in the soft woods.

Soft woods should not be steamed and bent, because they are very susceptible to injury by this process. When tested, the bent portion will be very weak and brash. A close examination will reveal numerous slight compression failures on the inner curve of the bend. Spruce is particularly subject to this type of injury.

SEASONING.

It is well established that a decrease in the moisture content of wood after the fiber saturation point is reached results in marked progressive increase in the strength of wood, accompanied by a decided shrinkage (63). The fiber saturation point is the condition at which the cell walls are completely saturated, or, in other words, have absorbed the maximum percentage of water which they can hold, but the cell cavities are empty. For two reasons, then, to increase the strength and to prevent subsequent shrinkage when the pieces have been worked to size or even assembled, it is essential that airplane timber be dried or, as it is commonly termed, seasoned. This may be done by air drying, that is, natural seasoning in the air, or by kiln drying, that is, seasoning with artificial heat (4, 12, 64, 65, 66, 70).

As a result of improper seasoning, particularly that which occurs unevenly or too rapidly, checks, which are small longitudinal splits, may occur in the wood. Almost invariably these are on the tangential face, since wood as a rule shrinks about twice as much in the direction of the annual rings as it does radially or across them. The longitudinal shrinkage (with the grain) is so slight that it usually has no effect. Checks are decidedly weakening, but fortunately are easy to recognize.

Airplane wood is usually kiln dried, because the seasoning process can be better controlled than in air drying; it is more rapid, a lower moisture content can be attained, and there is less tendency for kiln-dried wood to shrink and swell with subsequent changes in the humidity of the air. Extensive tests have been made on the effect of artificial seasoning (73). Kiln drying when not properly done is a source of serious injury. Temperatures that are too high or proper temperatures that are combined with humidity that is too low may markedly weaken a charge of lumber, particularly if these conditions are maintained for some time. The detection of such injury, when not severe, is very difficult. Hence, it is highly important that self-recording instruments showing temperatures and relative humidities at all times be properly installed in the kilns and that these be calibrated from time to time. In pronounced cases the lumber will readily reveal its brittle nature when picked with a knife blade.

In all cases where it can not be determined satisfactorily by other methods, representative pieces should be selected for impact bending. This test above all others most readily reveals brittleness in wood. But the test must be made, or at least the results and breaks reviewed, by some one experienced in this method of testing and thoroughly conversant with the mechanical properties of wood.

COMPRESSION FAILURES.

Compression failures may be due to abnormal stresses on the standing tree (from a wind of unusual velocity, for example), to shocks in felling the trees, or to injury during the process of manufacture. Figure 2 shows a compression failure, probably caused when the tree was felled, in a section from an unfinished wing beam of Sitka spruce. As an example of injury during the course of manufacture, it might be mentioned that when a large number of wing beams, improperly piled, are transported on a car or wagon the weight and jar sometimes cause such failures in beams near the bottom of the pile.

The smaller compression failures are not easy to detect. They appear as small whitish wrinkles or irregular lines across the face of the piece, at right angles to the grain. A hand magnifier is often necessary to bring out the finer failures distinctly.

The more pronounced failures appear as rather rounded ridges resulting from the "buckling" of the wood fibers under stress.

Compression failures are quite detrimental to the strength of wood, particularly as regards bending strength and shock-resisting ability. Material showing compression failures must not be used in parts where strength is required. One visible small compression failure usually indicates the presence of others.

Members with a small cross section are sometimes subjected to a rough test which makes the wood appear to be brash. It is well known that beams when placed in static bending characteristically fail first in compression, that is, in the fibers between the center (neutral plane) and the top of the beam. Hence, when a spruce longeron, for example, is supported at both ends and a load applied in the center, slight and practically invisible compression failures may result. Such failures appear as tiny whitish lines or wrinkles on the surface of the wood. If the member is then turned over and the load again applied until failure occurs, the break will be sharp and straight across with no splintering, typical of a compression break. This test should not be applied to softwood longerons, particularly spruce, since the resulting breaks will nearly always be

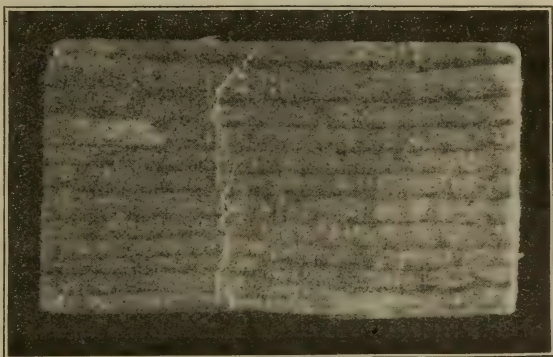


FIG. 2.—Section from an unfinished wing beam, showing a compression failure in Sitka spruce which probably occurred when the tree was felled.

short and sharp and may be confused with breaks in brash wood. By turning the member over after the first weight is applied, the compression side, already partially failed, becomes the tension side under the new load; and when the new compression side fails, the tension side, already fractured squarely across, fails with it. To test the resiliency of such members, apply the load on one side only, and do so with moderation.

SHAKES.

Shakes are long tangential cracks or separations in the wood fiber. They are the result of an actual rupture of the wood due to wind, felling stresses, or other causes and are exceedingly detrimental to strength. Old shakes which have occurred while the tree was still standing are often stained and readily visible to the naked eye. This is also true where lumber has been exposed to the weather and dirt has filtered into the cracks. But where they are neither discolored nor opened up the rupture is not so easily detected.

PITCH POCKETS.

Pitch seams or pockets are lens-shaped cavities or openings between the annual rings. They contain resin or pitch either in solid or liquid form; hence the name. These defects result from injury to the living tree, but the cause of injury is as yet unknown. Pitch pockets may indicate more serious wounds. They are very common in Douglas fir, but may be found in other resin-producing softwoods, including spruce.

While pitch pockets reduce the strength of wood, the reduction is not as serious as is generally supposed. General specifications regarding the presence of these defects have been worked out for wing beams of spruce and Douglas fir (69, p. 21).

WORM HOLES.

Worm holes are caused by the larvæ of three main types of wood-boring insects. The powdery or granular matter, the excrement or frass of either the adults or the "worms," or larvæ, with which these galleries or burrows are usually filled, need not be confounded with decay, since there is no difficulty in separating the two defects. In decay the transition from the soft, spongy, or friable wood to the normal hard material is gradual, while in the worm holes, usually circular or somewhat flattened when seen in cross section, the line between the firm wood and the frass or finely excreted wood is very sharp.

(1) Ambrosia beetles or "pinworms." The small adult beetle bores into the green saw log or green lumber and deposits its eggs. The larvæ hatching from these eggs extend other burrows at an angle from the parent galleries. Moisture is necessary for this type of insect. There may be a blackish discoloration extending around the galleries, particularly those in the sapwood. This is the result of the activity of a wood-staining fungus which does not cause decay in the wood and therefore need not be considered as weakening the material.

(2) Borers. The adults of borers, as a rule, require bark under which to lay their eggs. The larvæ hatching from these eggs burrow under the bark through the sapwood and sometimes into the heartwood; the holes are often large.

(3) Powder-post beetles. Powder-post beetles cause the most dangerous type of defect, and their presence may be detected by fine, powdery droppings coming from the wood. The eggs are laid either in the pores of the wood or under the bark, depending upon the type of insect causing powder post.

Worm holes not only weaken the wood, but the presence of the larvæ of powder-post beetles in the wood may render it unsafe. Ambrosia beetles or borers already in the wood can be killed by the ordinary dry-kiln process, but certain types of powder-post beetles require higher temperatures. It is much simpler to prevent attack, and this can be done by slight modifications in business management.

Full information on these and other insect defects can be obtained from the Bureau of Entomology, United States Department of Agriculture.

CHARACTERISTICS OF SPECIES.

Different woods have certain inherent qualities which must be recognized. Douglas fir has a decided tendency to splinter. The separation usually occurs along the annual rings in the spring wood adjacent to the summer wood. It is quite probable that this characteristic can be accentuated by excessive steaming with high temperatures during kiln drying, since it has been shown (61) that certain softwoods in which the spring wood is sharply differentiated from the summer wood, in which category Douglas fir belongs, have the spring wood weakened more easily than the summer wood by prolonged boiling. On account of this tendency of Douglas fir to splinter, aside from other reasons, Sitka spruce and Port Orford cedar are more desirable.

White elm can be readily steamed and bent, but it usually warps and twists badly in drying. Douglas fir is very subject to splitting when nailed, while basswood is one of the least troublesome species in this respect. Black ash is low in stiffness. Other examples might be cited, but these are sufficient to show that the failure of a wood to meet certain requirements may be unavoidable.

FAULTY DESIGN AND ASSEMBLY.

As an example of faulty design the following instance may be cited. In one of the types of combat planes constructed in the aircraft factories of this country two horizontal bolts were placed directly through the neutral plane in each upper front longeron of Douglas fir. A fitting was hung on the head of these bolts and two opposed high-tension wires, pulling at right angles to the direction of the grain in the longeron, were attached to the fitting. While the ship was subjected to shocks and jars which occur particularly during landing, these wires were in very unequal and irregular tension, varying from loose to very tight, and the strain on the longeron was exactly the same as if a chisel blade had been inserted through the neutral plane and the handle was being jerked sharply up and down. On the test flight of the first ships built the longerons did the obvious thing; they split in both directions from the bolts for a distance of a few inches to 2 feet. The failure was promptly blamed on the wood, which was assumed to be either weakened by decay or faulty kiln drying, instead of on the faulty design, where it belonged. Such mistakes arise from the lack of knowledge of the mechanical properties of wood on the part of the designer.

Incorrect assembly also plays a part in the unjust condemnation of perfectly good wood. One of the most common occurrences was to have interplane struts of Douglas fir or spruce, especially the

latter, reported as being made from decayed or "dead" wood. This was characterized by the fact that the struts, after assembly, if struck sharply on the side near the middle, would "bow" and remain in such position. If struck then on the opposite side the "bow" might reverse, but the strut rarely straightened up. This condition results from such an excessive tightening of the drift and flying wires that the struts acting as posts between the wings are placed under such a heavy compression load that they are just on the point of failure, hence the inability to straighten up after bowing. Needless to state, such a condition is dangerous.

Figure 3 shows a compression failure in the head of a vertical fuselage strut due to severe tightening of the tension wires in the fuselage. This failure occurred before the machine had left the factory floor.

In the foregoing pages no attempt has been made to specify all the defects in airplane timber aside from decays or discolorations, or to describe fully those mentioned. The writer desires merely to call the attention of the reader to defects that can receive only passing mention or must be omitted entirely, so that, if interested, he can become conversant with these through the references cited.

COLOR COMPARISONS.

Color is a natural characteristic of wood while still in the living tree. For the first few years after formation wood is white or nearly so, and finally when the sapwood is transformed to heartwood a decided color change takes place in most woods, while in some the change is negligible. In such species as redwood (*Sequoia sempervirens* (Lam.) Endl.), incense cedar, Douglas fir, juniper (Juniperus), white ash, true mahogany, and white oak there is a decided contrast between the light-colored sapwood and the dark heartwood, while in spruce,

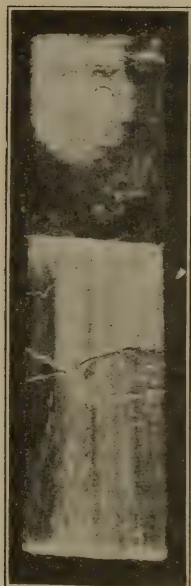


FIG. 3.—Head of a fuselage strut, showing a compression failure in Sitka spruce caused by an excessive tightening of the tension wires in the fuselage.

fir, western hemlock, and yellow buckeye (*Aesculus octandra* Marsh) the heartwood more nearly approaches the sapwood in color, and in some cases it is difficult to distinguish between the two. Color is not always uniform in the heartwood. It is necessary to be thoroughly acquainted with woods to be able to recognize normal color variations at a glance.

Color should always be observed on a freshly cut surface and the surface (whether radial, tangential, or cross) recorded when making permanent observations. All woods change color on exposure to light and air (54), the most noticeable change occurring in the lighter colored woods, particularly of the conifers. The first change is a yellowing, then a graying, and finally in some conifers a decided browning. These color changes have no weakening effect on the mechanical properties of wood, since the discolored portion is a very thin surface layer and microorganisms play no rôle in this change

of color. Light is necessary. Ordinarily these color changes are deepened by direct sunlight, which has a greater influence on the color changes than diffused light.

Green wood usually differs in color somewhat from air-dry material of the same species, even on a freshly cut surface. There is a tendency for the more delicate tints to be obscured by drying. A system of color standards is at present sadly needed in describing colors of wood (53). Furthermore, the condition of the wood, that is, whether green, partly air dry, or fully air dry, invariably should be given consideration.

The heartwood of sugar-pine, eastern white-pine (*Pinus strobus* Linn.), and western white-pine lumber often becomes a pink, light-red, or vinous-red color upon air drying. This color is not confined to the surface layer, but is usually uniform throughout. No reduction in strength results. Wood of this kind is very pleasing to the eye, so it is often desired by pattern makers. This discoloration need not be confused with an incipient decay, since it is so uniform throughout. Furthermore, it terminates abruptly in a horizontal direction and does not shade off gradually into the normal light-brown or cream-colored wood.

Color is considered an index of strength properties (14, p. 359-360) in certain cases. The French marine department distinguishes two classes of European oak (*Quercus robur* L.), inferior wood (bois maigre) and good wood (bois gras). The former, which is straw yellow in color on a fresh cut, is much more subject to atmospheric influences; that is, it shrinks, swells, warps, twists, and splits more readily than the latter, which is pale brown to red brown in color. This is taken into account in specifying in what part of the construction the two types of wood shall be used. The Danish-Prussian marine specifications distinguish three colors of green oak wood, whitish yellow, brownish yellow, and reddish yellow, all three frequently with a tinge of gray. The first color on drying becomes straw-colored or sand gray, the second greenish brown, and the third reddish yellow or a dirty or dusty yellow-brown. It is considered that the unseasoned or fresh wood with any brownish color is decidedly poor in quality.

The foregoing seems to be somewhat contradictory. In the opinion of the writer, trusting to the vagaries of color is an exceedingly uncertain method by which to judge the strength properties of wood within a species or group and has nothing to recommend it as compared to the reliable index of the ratio of summer wood to spring wood per annual ring, which is particularly easy to judge in ring-porous woods like oak. There is a widespread opinion in regard to southern bald cypress (*Taxodium distichum* (Linn.) Rich.) that the darker the heartwood the more durable it is, but in reality the color of the heartwood makes no difference.

Most woods when dried after a prolonged immersion in water reveal a grayish, lusterless color, much like that caused by steaming (see p. 10). Oak changes to a blue-black or a gray-black color after such treatment.

Wood becomes a dirty gray to gray-black color after long exposure to the elements. This is well illustrated by unpainted poles, fence rails, posts, and shingles. The color change is caused by a number

of factors (52), but most important is a chemical reaction in which iron plays an important part. Timber is not weakened by this discoloration, since the action is confined to the surface.

In boards cut from red cedar (*Juniperus virginiana* Linn.) white streaks are frequently found mingling with the normal red heartwood. Such streaks are the white sapwood, the mingling being due to the irregular outline of the stem to which the heartwood conforms or to layers which never change to heartwood.

In Sitka spruce the heartwood has a light reddish tinge, slightly distinguishing it from the sapwood. Some trees of Sitka spruce, however, have a pronounced reddish or brownish pink heartwood, which is quite uniform throughout. The color difference is striking in a planed board or timber containing both heartwood of this kind and characteristic white sapwood. The same phenomenon undoubtedly occurs, in red and white spruce, where it would be even more noticeable, since the heartwood in these species is normally as light colored as the sapwood. This reddish heartwood is just as strong as wood of the usual color and can be safely utilized. The same condition is reported as being quite common in the Himalayan spruce (*Picea morinda* Link) in India (16, 29).

The brown heartwood of incense cedar (8, p. 22-24) and western red cedar often has a reddish to purplish tinge, varying in intensity even in the same piece, while in other trees it may be completely lacking. It is entirely without significance in relation to the strength of wood so affected.

In certain softwoods color variations may be connected with changes in the rate of growth. In the heartwood of Douglas fir, which has a distinct reddish or orange-reddish hue, the reddish color may be strongly intensified in long regular bands. A careful examination will show that this color change is confined to a definite group of annual rings, narrower than those on both sides or containing a greater proportion of summer wood. The brown heartwood of the cedars also varies in this way. The so-called "yellow fir," from the slowly grown, exceedingly narrow ringed outer layers of the old coast Douglas firs, is another example. The origin of such variations can be readily recognized, since the color is confined to a definite group of annual rings.

Occasionally an apparent discoloration in heartwood may be due to the failure of the wood to change color uniformly during the transition from sapwood to heartwood. This has been noticed in white ash, Douglas fir, western red cedar, western larch (*Larix occidentalis* Nutt.), and other woods. The sapwood of white ash is white or straw colored, while the heartwood is grayish brown, sometimes with a reddish tinge. Hence, when the condition above mentioned is found, the grayish brown heartwood will contain sharply delimited straw-yellow areas of various sizes and shapes. The wood is not weakened. How to avoid confusing this condition with the initial stages of white-rot will be considered later.

Discoloration may be caused by dirt or dust. Surfaced or sanded white pine or sugar pine is sometimes found covered with tiny little grayish black streaks following the grain of the wood. A close examination will show that this is due to deposition of dust in the numerous resin ducts. This is especially apparent against the almost

white wood of these species, whereas in darker woods the streaks would pass unnoticed.

Burns or scorches in wood may occur from the use of high-speed saws if the saws are not set properly to provide sufficient clearance. Improperly set planing knives will produce the same effect. Usually such burns, appearing on the face of the piece as dark-brown to blackish blotches, are very superficial and can be planed off. The injurious effect is negligible. Deep burns, extending through a piece one-eighth or even one-fourth of an inch in thickness are rarely encountered and are usually confined to particularly susceptible woods, such as the white pines. These may result when a high-speed sander stops suddenly. The wood is injured and can not be used for highly stressed parts. Burns usually occur in the remanufacture of dry lumber and not on green lumber in the mills.

DISCOLORATIONS CAUSED BY WOUNDS.

The term "wounds" as applied to trees includes not only those scars by which the bark is removed from living trees, exposing the sapwood or heartwood with the death of the cambium over the exposed surface, but also those injuries by which the cambium is temporarily damaged but not killed. The cambium, which is very susceptible to injury, is the very narrow layer of delicate growing tissue of a tree situated at the junction of the living bark and sapwood. When this tissue is injured or killed, a healing or callusing process immediately begins which causes a dip or wave in the grain. Consequently, irregularity of grain in a timber often indicates proximity to a wound.

Wounds in living trees result from a variety of causes, among which may be mentioned fire, lightning, insects, birds, and man. All such injuries are usually accompanied by a discoloration of the wood, particularly the sapwood. Such discolorations are most intense in the hardwoods, especially in the sapwood of such species as white ash, hickory, maple, birch, and tulip poplar.

When the wood of a living tree is exposed to the air it dries out and changes color. In softwoods the change is to a grayish brown or dead-gray color, while in hardwoods the change ranges from a deep brown to almost black, most noticeable in the sapwood. This color change is an oxidation process. Although the wood is not weakened by this change, wound wood of this type should be avoided, owing to the fact that during its exposure to the air it often becomes infected by wood-destroying fungi and may be weakened by incipient decay.

LIGHTNING WOUNDS.

The general appearance of lightning injury is readily recognized. Spike tops and stag heads, together with the spiral wounds existing for many feet along the trunks of the trees, are unmistakable.

Besides such wounds, the cambium is very susceptible to electrical discharge and may be affected for some distance down the tree without any outward visible indications. This irritation to the cambium results in the formation of a layer of cells changed in both shape and structure from the normal. Often in the conifers an unusually large number of resin cells or resin ducts are formed within this injured

portion. In a short time the cell formation returns to normal. Ultimately, as the growth of the tree proceeds, these lightning rings, always following one definite annual ring, are deep within the wood, extending completely or partially around the circumference over a varying distance. When the tree is worked up for lumber certain of the boards may have such lightning rings extending completely through, both in width and length. Such a board then consists of two layers of wood held together by a zone of abnormal structure forming a plane of cleavage. Checking often occurs along this line, since the continuity of the medullary rays may be interrupted. Such checks are striking, since they invariably are tangential, following an annual ring on end section or radial face but not visible on the tangential face. This

is not at all an uncommon defect in air-plane timber. An abnormal number of resin ducts may be found in the annual ring following many types of mechanical injury, but for practical purposes there is no difference between such so-called traumatic resin ducts and the abnormal ducts formed as a result of lightning injury.

It is self-evident that wood with these lightning rings must be used with discretion. Even though the lightning ring does not check on drying, when a member with this defect is put under severe strain and stress a



FIG. 4.—Section from a finished interplane strut, showing a small lightning injury in Sitka spruce.

serious check may develop. Of course, every member showing a lightning ring need not be considered valueless. Such a defect in the stream line of a strut, for example, would be trifling, while a much shorter ring in the butt or inner bay of a wing beam, particularly if in the same plane as the bolts, would be serious. The same ring in the tip of such a beam could be overlooked.

The detection of lightning rings in rough lumber is exceedingly difficult, unless accompanied by small wounds, which is sometimes the case. Then such wounds must be scrutinized closely for the presence of a lightning ring. Two or more of these wounds, which resemble sapsucker wounds, occurring on the same annual ring and connected by a lightning ring, are sometimes found. Figure 4 shows one of these wounds on an interplane strut, in this case not of

any importance, since the injury occurred alone with only a very short lightning ring and on the stream lining where high strength is not requisite. Lightning rings are more readily detected on a member before it is sanded. In some cases the seriousness of the defect can be determined after planing but before the piece is shaped. This is usually possible when the defect runs entirely through the piece.

In white fir the lightning rings are easily detected both on cross section or on the radial face. The normal color of the summer wood is a light brown, while the lightning ring is a pronounced brown or purplish brown, which stands out strongly against the whitish sapwood or heartwood. Abundant resin ducts occur in these rings.

Lightning rings in incense cedar are dark brown in color, standing out plainly in the white sapwood, but are not so apparent, although still recognizable, against the reddish brown heartwood. Resin ducts do not accompany lightning rings in cedar.

Sitka spruce wood is rather susceptible to the effects of electricity. The lightning rings appear as light to dark brown lines in the pale pinkish heartwood or white sapwood. Rings are found which appear to be chiefly composed

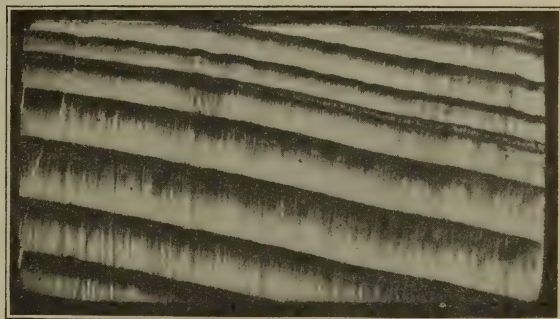


FIG. 5.—Cross section from an unfinished elevator beam, showing a lightning ring in Sitka spruce. The row of resin ducts extending entirely across the section can be seen in the summer wood of the fifth annual ring from the bottom. The defect ran the entire length of the beam.

of resin ducts; in fact, when viewed on the end section, it is seen that the resin ducts are so numerous that they almost coalesce. This condition is illustrated in Figure 5. Furthermore, spruce wood is peculiarly susceptible to discoloration by lightning injury. Often in connection with a lightning ring a reddish brown discoloration is found, somewhat tinged with purple. This discoloration rarely extends radially more than 3 or 4 inches from the lightning ring toward the pith, but may extend 2 feet beyond the limits of the ring in a vertical direction. Wood so discolored is not weakened. Furthermore, the color is not sufficiently intense to detract from its value for any purpose, particularly since the discoloration when varnished appears merely as a darker tone of the normal heartwood.

The lightning rings found in Douglas fir are red-brown in color, darker than the summer wood and consequently are quite apparent in the white sapwood and orange-red or yellowish heartwood. These rings are practically composed of resin ducts. The ducts are smaller than in Sitka spruce.

The reader must not get the impression from what has been written that lightning rings are a feature of every piece of wood, but they do occur and must be taken into account.

SAPSUCKER WOUNDS.

Sapsuckers are a group of woodpeckers which extract the sap from the inner bark and sapwood of living trees and eat the cambium. The final result after the wound has healed or callused over is the so-called bird pecks (15, 35). This injury is often accompanied by extensive staining, particularly in the hardwoods. On the ends of logs or boards the healed wounds appear as stained areas of varying size, each containing a more or less open, short, radial check in connection with distorted grain. The general appearance is a T-shaped or triangular mark or check surrounded by a stain varying from brown to almost black. More than one usually occurs in the same annual ring. On the edge-grain or slash-grain faces of sawed lumber these injuries usually appear as small knots or distortions in the grain, surrounded by more or less stain which is usually localized, but the stain may be accompanied by a bleaching which extends for some distance. The stain is always adjacent to the distorted grain, and the more distorted the grain the greater the extent of the stain.

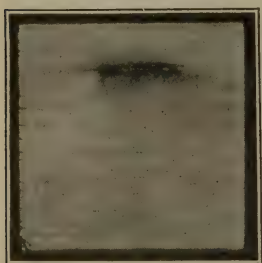


FIG. 6.—Section from a finished longeron, showing a sapsucker injury or bird peck in white ash.

The stain appears to be the most injurious of the two, but in reality the distorted grain is the only cause of weakening in the wood. The strength of the wood is not much affected, so that wood with bird pecks in most cases can be safely utilized. Figure 6 shows a section from a white-ash longeron with a minor injury of this kind which does not impair the usefulness of the member. Pieces are sometimes unsuitable for handles, owing to the tendency of the grain to roughen up at these places when planed. If the pecks are numerous in one annual ring it is best not to

use the piece, for although it has not been determined by comparative tests it is quite probable that such material is reduced in strength. Checks or wind-shakes are very prone to occur along an annual ring containing numerous sapsucker wounds or even at individual injuries. These often prove to be serious in thin veneer, since pieces of the distorted grain are likely to fall out. Sapsuckers are responsible for much of the curly grain and bird's-eye found in tulip poplar. Both stain and bird's-eye in this species are shown in Figure 7.

Practically all tree species, both softwoods and hardwoods, are subject to this type of injury, but hard maple, soft maple (*Acer saccharinum* Linn.), tulip poplar, and hickory in particular stain badly. The bird pecks are common in white ash, but the accompanying stain is generally closely localized.

PITH-RAY FLECKS.

Pith-ray flecks, which are also termed medullary spots and pith flecks, are caused by the larvæ or grubs of certain insects living in the cambium of living trees during the growing season (10, 17, 20, 21, 44, 67). These insects comprise several species of the genus *Agromyza* belonging to the order Diptera. On the end section of logs or lumber the flecks appear as small brown crescent or half-moon

shaped areas, which on the tangential or slash-grain face and the radial or edge-grain face of a board appear as brown streaks, usually running in a vertical direction. (Figs. 8 and 9.) The wood for a little distance around a pith-ray fleck may be darker than normal. This is particularly so in poplars or cottonwoods (*Populus* spp.). On the whole, the injuries are not at all serious, having no noticeable effect on the strength of the wood unless the flecks are exceedingly

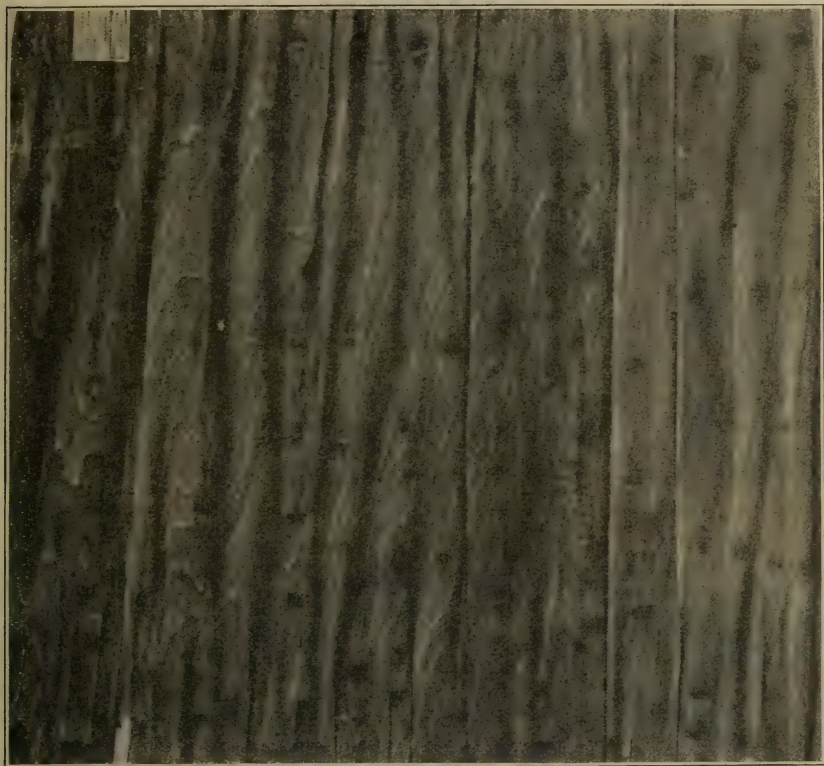


FIG. 7.—Slash-grain or tangential surface of a tulip-poplar board, showing stain and bird's-eye caused by sapsuckers. One-third natural size. (Courtesy of the U. S. Biological Survey.)

numerous. Only in the cherries (*Prunus* spp.) may a weakening be expected, for there the affected wood tissues are broken down, while in the other woods they are but little distorted. Furthermore, the presence of pith-ray flecks is usually hard to detect in the heartwood of cherries. The color of the heartwood differs but little from the color of the pith-ray flecks.

Pith-ray flecks are found in all the common poplars or cottonwoods, birches, maples, cherries, basswood, and many others, but there is considerable variation in their abundance on different closely related species. For example, these flecks are very common in soft maple, while they are rather infrequent in hard maple. In river, gray, and paper birch (*Betula nigra* Linn., *B. populifolia* Marsh, and *B. papyrifera* Marsh) they are found in abundance, but are

somewhat uncommon in yellow birch, although the writer has found them from time to time in propeller stock of this species. Softwoods

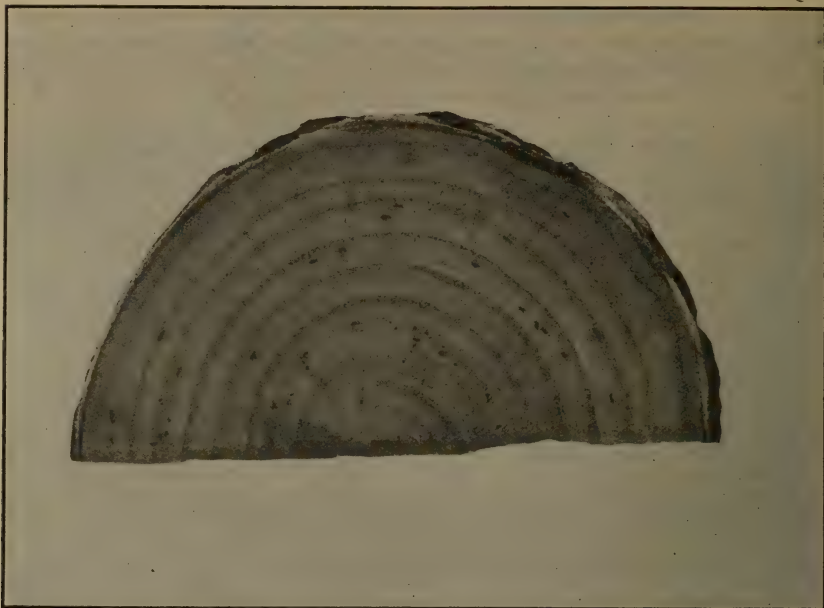


FIG. 8.—Transverse section of a branch of river birch, showing pith-ray flecks. Natural size.

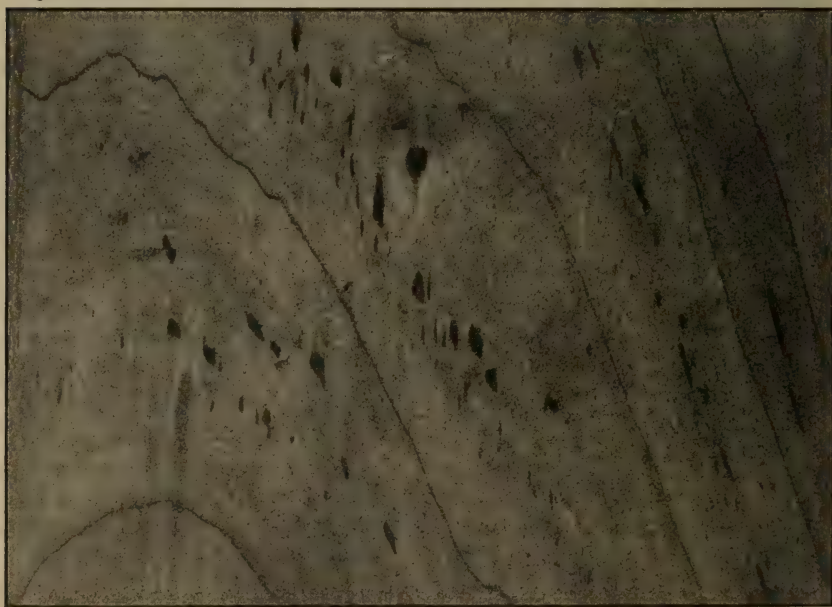


FIG. 9.—Tangential section of the trunk of a tree of silver maple, showing pith-ray flecks. Natural size.

are not subject to these pith-ray flecks, but a somewhat similar injury in western hemlock known as black check results from the work of a different insect (11).

CHEMICAL DISCOLORATIONS.

The sapwood of many species of wood is subject to discolorations, varying widely in appearance but fundamentally the same, which are the result of chemical action (3). Sapwood is rich in organic compounds and also contains certain soluble ferments which facilitate the oxidation of such compounds. Under favorable temperature conditions, for example, when green sapwood is exposed to the oxygen of the air, these ferments, known as oxidizing enzymes, act on the organic compounds in the sapwood. The result of their action, which is an oxidation process, is a discoloration of the sapwood, with the colored substance most noticeable upon microscopic examination in those cells mainly concerned in the storage and transportation of food.

Hot, humid weather is most favorable for this staining. Cool, dry weather retards it or prevents it entirely. Logs immersed in water are not affected. Light is not necessary for this reaction, as it takes place just as readily in darkness. The stain is confined to the immediate surface layer, and the wood is not weakened. The most practical method of prevention, if this is considered necessary, is by dipping the green sap boards into boiling water for a few minutes as they come from the saw.

HARDWOODS.

Birch, maple, and cherry stain a reddish yellow or rusty color. The wood of alder becomes very intensely red or red-brown on freshly cut surfaces, often within an hour or so after the surface is exposed (40). In the case of red alder (*Alnus oregona* Nutt.), if the wood dries and remains white, the red color will appear upon the addition of water in the presence of air, provided the temperature is favorable. A bluish stain often occurs in red gum (*Liquidamber styraciflua* Linn.).

The European linden (*Tilia europaea*, Linn.) is subject to a striking discoloration (39), which probably also occurs on basswood in this country. When freshly sawed boards are so closely piled that they dry slowly, a more or less apparent dirty green color appears in from 8 to 10 days. Under very favorable conditions the color is exceedingly bright and intense. The color varies between wide limits, from yellow-green or brown-green through all possible gradations to the purest moss green. Only the outer layers of the wood are colored. Usually the stain extends to a depth of one thirty-second of an inch or rarely to a depth of one-eighth of an inch. The staining, although it is the result of a chemical reaction (an iron-tannin reaction), is not dependent on temperature, since it occurs just as readily in winter as in summer. Too much moisture hinders the reaction, but a certain degree of moisture is essential. If the boards are dried quickly no staining results.

SOFTWOODS.

Coniferous woods are not so commonly subject to this type of discoloration, but there are a few examples. The ends of incense-cedar

logs sometimes have a decided brownish red stain on the sapwood. This is of no importance, because it does not occur on sawed lumber except so faintly as to be almost invisible.

A very unsightly discoloration known as brown-stain (43, p. 305-307), which, however, does not weaken the wood, often occurs on sugar pine, but is frequently not noticeable until the lumber has been finished. This appears in the sapwood as a streaky, dirty, light to dark brown or brownish black discoloration, and may be superficial or very deep. It is quite striking against the faint yellowish white sapwood in finished lumber. The discoloration occurs on green sap lumber upon exposure to the air and may appear during air drying or kiln drying. In the last instance it is known as kiln burn, but it does not differ from the brown-stain and is probably sometimes due to defective circulation in the kiln. Brown-stain is particularly bad in lumber cut in early spring. Hot, humid weather and poor circulation of air in the lumber piles favor the staining, while cool, dry weather and proper piling tend to prevent it. This brown stain is an oxidation process similar to the others, but whether it can be prevented by the hot-water treatment is doubtful, since the discoloration often extends deeply into the lumber.

The wood of sugar pine in dead trees, standing or down, may be affected by a very brilliant orange stain which occurs in spots or as a solid color, but more often is seen as narrow to broad streaks parallel to the grain of the wood. It is found in both heartwood and sapwood. The exact cause of this discoloration is unknown, but it is probably the result of chemical reaction, since no fungous mycelium has been found associated with it. While the wood is apparently not weakened, the presence of this stain indicates that the lumber came from dead trees, and it should be closely watched for signs of decay and insect borings.

DISCOLORATIONS CAUSED BY FUNGI.

From an economic standpoint by far the most important discolorations in wood are caused by fungi. Fungi are very simple plants which can not live on the simple food elements of the soil and air and build up complex organic matter, as is done by the green plants with which we are familiar, but must have organic matter already prepared in order to sustain life. This they find in the material built up by green plants; hence they may attack living plants, or dead portions of such plants, or any dead vegetable matter. Some live on animal matter, but these do not concern us. The development of fungi is dependent upon a supply of oxygen, of which there is always sufficient in the air, a certain degree of moisture, a suitable range of temperature, and the necessary food substances. The maximum and minimum of these requirements vary widely with different fungi.

The fungous plant consists of very fine threads (hyphæ), which are invisible to the naked eye unless they occur in mass. Individual hyphæ require magnification by a compound microscope. Collectively, the hyphæ are termed mycelium. The hyphæ usually live in the tissues of the substance on which the fungus is growing. The fruiting bodies or sporophores, which vary in size from those so small as to be invisible to the naked eye except in a mass to others quite

large and conspicuous, appear on the surface after the hyphæ have developed vigorously. The fruiting bodies bear the spores, which are microscopically small reproductive bodies of relatively simple structure. The spores, being very light, are borne about by air currents. If they alight in a suitable place under proper conditions, germination takes place and hyphæ develop.

Fungi growing on wood may be roughly divided into two groups, depending on the habit of growth of hyphæ. In the first group are placed those fungi whose hyphæ live on the substances contained in the various cells of the wood, while to the second group belong those whose hyphæ attack the actual wood substance of the cell walls and destroy it. The first group is principally represented by the sap-staining or discoloring fungi, so called because they produce various discolorations which are confined to the sapwood. To the second group belong the wood-destroying fungi.

SAP-STAIN.

DESCRIPTION.

Sap-stain, which has been extensively studied (23, 27, 38, 50, 51), even though it may render wood very unsightly does not reduce its strength for practical purposes. The discoloration is normally limited to the green sapwood, because as a rule there is neither sufficient food material nor moisture in the dry dead heartwood for the development of the fungus. The discoloration is usually most intense in the medullary rays, since in these tissues the bulk of the food material is found. The stain is produced in two ways, either by a reflection of the color of the hyphæ through the cell walls of the wood or by an actual color solution excreted by the hyphæ, which stains the wood itself. These stains vary in color from blue or blackish to reddish, the former being the most common. Since these fungi do not attack the cell walls in which the strength of the wood reposes, except to a negligible extent, discolored wood is not appreciably weakened. This has been determined by comparative mechanical tests on stained and unstained wood (41; 56, p. 13-14; 72, p. 17).

Although the strength of the wood fibers is not impaired by such stains, the wood is objectionable in places where color is a factor. In a highly varnished interplane strut, for example, a stained streak is unpleasant to the eye. Furthermore, it may lead to a strong prejudice against the airplane having such a member, because while by the uninitiated a dangerous defect not readily apparent is passed unnoticed, an unsightly though harmless discoloration is considered to indicate a serious weakness. Where the discoloration is to be covered up or painted there is no reason to exclude it.

It must be remembered that the conditions which promote the development of the fungus discoloration are highly favorable to the development of true wood-destroying fungi. These conditions are a comparatively high humidity and warm weather. Sap-stain is at its worst during warm wet weather, when the humidity of the air is relatively high and lumber dries slowly. It is at such periods that the most severe staining may occur if the lumber is not properly handled. The climate of the Pacific Northwest is usually exceed-

ingly favorable for the development of wood-staining and wood-destroying fungi during the spring and summer months. It is from this region that the three most important airplane woods—Sitka spruce, Douglas fir, and Port Orford cedar—are obtained.

Wood containing very severe sap-stain therefore should be carefully examined for the presence of wood-destroying fungi. If decayed, the wood will be brash and may be softer and less tough when the fibers are picked with a knife. If any doubt exists after an inspection, the decision should be based on a microscopical examination or a mechanical test by a qualified expert.

The most important of these stains from an economic standpoint is blue-stain, caused by various species of *Ceratostomella*, which may be found on almost any hardwood or softwood. Softwoods are more commonly affected, and certain species are particularly susceptible. This is due both to the character of the wood and to the climatic conditions of the region where the species occurs. The discoloration may be more or less superficial, occurring as spots or streaks. If the staining is severe, however, the entire sapwood will be affected, so that it can not be surfaced off. The fungi causing these stains are not readily seen, but sometimes if a deeply stained, almost black piece is inspected with a hand magnifying glass, innumerable bristles with a bulbous base will be observed. These are the fruiting bodies, containing an enormous number of spores, which are exuded and are carried about by air currents. Falling on green sap lumber they sprout, the hyphæ develop, and more blue-stain results. Under favorable conditions blue-stain may develop with surprising rapidity, appearing on lumber within a day after sawing.

Other colors, such as black, brown, gray, red, pink, and violet, are caused by species of *Hormodendron*, *Hormiscium*, *Graphium*, *Penicillium*, and *Fusarium*. These discolorations are not nearly so common as blue-stain.

Certain other discolorations of sapwood are produced by fungi belonging to the molds, of which the green mold on fruits or in certain cheeses is an example. Usually such stains are superficial and readily surface off. They occur on both hardwoods and softwoods. The bluish or blackish stains are difficult to separate by visual inspection from the true blue-stain.

CONTROL.

Considerable study has been devoted to the development of methods of prevention and control of sap stains caused by fungi (1, 25, 72). Naturally most of this work has been concentrated on blue-stain, and the following paragraphs are most directly applicable to it, but will probably also apply fairly well to the others. Blue-stain may be checked after it has started, but the stain can not be eradicated unless it is so superficial that it can be planed off. Therefore, the keynote of all treatments must be prevention.

Unfortunately, there is no one principle that can be applied to the prevention of this discoloration. Staining may take place at any time after the trees are felled or, in the case of dead timber, while they are still standing. Hence, in logging operations in regions where blue-stain is of importance, the logs should be removed from the woods as soon as possible after the trees are felled and bucked

(cut up into log lengths). The practice of leaving logs lying in the woods for months can not be too strongly condemned, as this not only causes blue-stain but also promotes the growth of wood-destroying fungi. Furthermore, the inevitable attacks of wood-boring insects assist greatly in the spread of blue-stain and decay. When the trees are bucked the narrow space left by the saw kerf between the logs as they are lying end to end affords an ideal situation for the development of the blue-stain fungi. Such logs often stain deeply, while those with the ends fully exposed remain entirely free from discoloration. As soon as the logs are in the mill pond danger from staining is over for the time being, since the oxygen supply is so reduced that the fungi can not develop.

The greatest danger of all is encountered during the process of drying the rough lumber as it comes from the saw. The best method of preventing blue-stain is by kiln drying. If the stock checks easily, so that low temperature and high humidities must be maintained over a considerable period, some of the other staining fungi such as molds, may develop. But these can be checked by raising the temperature in the kiln to about 160° F. or slightly more for an hour by turning live steam into the kiln. When this is done, care must be taken to keep the air saturated while steaming and to reduce the humidity gradually after steaming. When the stock has once been dried properly the moisture content has been so reduced that there is no more danger from staining, provided it is kept dry. A dispute that arose over the efficiency of a dry kiln was immediately settled by the fact that the blue-stain fungi had resumed vigorous growth the day after the stock was removed from the kiln. This could not have occurred if the lumber had been properly dried.

All airplane lumber should be kiln-dried immediately, since this not only prevents blue-stain, but also stops the growth of wood-destroying fungi, prevents future checking, and greatly reduces weight without in any way injuring the lumber, provided temperatures that are too high are avoided.

In case kiln drying is impossible, treatment with antiseptic solutions is of considerable value. As it comes from the saws the green lumber is dipped into a hot or cold chemical solution. The solutions most commonly employed are sodium carbonate or sodium bicarbonate in water. Neither is 100 per cent effective under optimum conditions for staining, but they aid materially in checking discoloration. These two chemicals, however, color the treated wood a decided yellow or brownish. Sodium fluorid, although it does not stain the lumber and is slightly better for blue-stain, is not so effective against certain molds as the two solutions first mentioned. This chemical is seldom used. It must be remembered that the strength of the solutions must necessarily vary with the conditions. The more favorable the conditions for blue-stain, the stronger the solutions should be.

After being dipped in any of these solutions the lumber must be carefully open piled, that is, with spaces between the boards to insure good ventilation. Narrow cross strips or "stickers" chemically treated should be used, to prevent staining at the points where the boards and cross strips meet. Detailed instructions as to the proper methods of piling lumber may be consulted elsewhere (4, p. 17-21).

Salt is of little or no value in preventing blue-stain in comparison with the other chemicals. The application of salt after blue-staining has well started is almost a waste of money. In fact, the application of wet salt or a strong salt solution may prove detrimental in the long run, for if the lumber is dried after such treatment the affinity of the salt for water may cause the moisture content to remain much higher than normal.

Mercuric chlorid in a 0.1 per cent solution is exceedingly effective against blue-stain, but on account of its highly poisonous nature and extremely corrosive action when in contact with many metals it is little used.

Shipping green stock closely piled in closed box cars during the spring and summer months is almost certain to result in severe staining. Indeed, the writer has seen some stock handled in this way which stained even in winter. On the other hand, any measures taken to prevent staining, such as open piling in gondolas or on flat cars, will almost certainly result in severe checking. Of the two evils, checking is by far the most serious in airplane stock, since checked lumber is greatly reduced in strength, while the stained lumber is only somewhat unsightly. Shipping green lumber in the close hold of a vessel, particularly if tropical seas are to be traversed, is an invitation to swift and sure disaster as far as sap staining is concerned. It is doubtful whether dipping in any chemical solution now used, except possibly mercuric chlorid, would be effective under such severe conditions.

But, to repeat, the most effective measure to employ against blue-stain is speed in drying the wood. Get the logs from the woods to the saw with the greatest rapidity and the lumber from the saw directly into the dry kiln.

SAP-STAIN ON SOFTWOODS.

Certain species are peculiarly susceptible to sap-stain. This is due both to the character of the wood and to the climatic conditions of the region where the species grows. Western white pine, spruce, and southern yellow pine, the last-named wood including longleaf pine (*Pinus palustris* Mill.), shortleaf pine (*P. echinata* Mill.), and loblolly pine (*P. taeda* Linn.), are very subject to sap-stain, especially blue-stain, while true fir and cedar are not so easily affected. Douglas fir occupies an intermediate position.

Besides blue-stain, a red stain has been very commonly found on Sitka spruce airplane lumber. It occurred abundantly in the East on stock in cars just arrived from the Pacific coast and also developed on material along the Atlantic coast which had arrived unstained at the port of embarkation but was held over awaiting shipment. The stain appeared as terra-cotta or brick-red spots on the rough lumber, varying from very faint to a pronounced color. In the stock worked up in the factories in this country it was found that the stain was superficial, usually surfacing out during remanufacture; but reports from abroad indicate that the fungus developed very intensively by the time the lumber reached European ports, and the discoloration penetrated deeply into the sapwood. The appearance of the wood is not marred to the same extent that it is by blue-

stain, and as far as is known no reduction in strength results. The fungus causing the discoloration is as yet unknown.

Blue-stain is very severe on the white pines and is particularly noticeable because of their white wood. Plate I, left part, shows a section from a sugar-pine rib web in which the sapwood is stained to some extent. The small, darker, bluish black spots are the ends of the medullary rays, in which, as before stated, the fungous mycelium is most abundant. The longer streaks are the resin ducts.

Certain fungi (*Penicillium* spp.), stain the sapwood of the pines an orange-red to a crimson-red color. Another fungus (*Fusarium roseum* Link) is responsible for a pink to lilac color in the same woods. The color is produced by means of a pigment secreted by the hyphae, which actually dyes the wood.

A wood-staining fungus (*Zythia resinæ* (Fr.) Karst.) has been reported in Europe (9) as working on finished pine lumber after the wood has been oiled. The discoloration was characterized by violet to dirty red or even dark grayish brown flecks beneath the oiled surface of the wood. The spots were covered with minute pustules varying from violet, orange, and brown to black. These constitute the spore-producing bodies. The discolored areas extend within the wood as streaks closely associated with the medullary rays and resin ducts. The report does not state whether the discoloration was confined to sapwood. Apparently the wood was not reduced in strength. As far as is known, this stain has not yet been found in the United States.

SAP-STAIN ON HARDWOODS.

Hardwoods are not as subject to the stains caused by fungi as are softwoods. In hardwoods, when sap-stain does occur, the discoloration is most intense in the medullary rays and large pores or vessels. In a wood such as yellow birch, in which these vessels are not too closely crowded, the stain, if not too severe, appears in longitudinal section as very narrow bluish black lines or streaks following the grain of the wood. This stain will not necessarily be confined to the surface layers, but may extend entirely through the sapwood. Of all the hardwoods, however, red gum seems to be the most susceptible to stains caused by fungi.

BROWN-OAK DISCOLORATIONS.

A somewhat different discoloration than those previously described, in that it is confined to heartwood only, is the "brown oak" (18, 19) found in Great Britain. This is also known as "red oak" and "foxiness," but the name first given is most commonly accepted. Instead of the normal heartwood, certain trees of the common European oak have a dull-brown to rusty brown or even rust color in the heartwood. In some cases the color is uniform, while again longitudinal streaks of normal-colored heartwood may alternate with those of the brown color. When these brown streaks contain black patches this type of wood is known as "tortoise-shell" oak. This discoloration originates in the heartwood of living trees, the normal heartwood changing first to a faint yellow color, which continues to deepen until the brown stage is attained. The color change is caused by a fungus, but so far as known the infected wood is not weakened.

The hyphæ attack the cell walls very slightly, presumably living on the tannin, of which oak wood contains a high percentage. The value of the wood for veneers is very much enhanced. The writer has no record of this discoloration being found on oaks in this country.

DECAY DISCOLORATIONS.

The hyphæ of wood-destroying fungi living within the wood feed on the various substances composing the cell walls. They use certain constituents of the cell walls, neglecting others, with the result that these walls are broken down, the wood being thus greatly weakened and more or less destroyed. It is the breaking down of the wood and the change in its physical and chemical qualities that is termed decay. The degree of decay is determined by the energy of growth of the fungus, the length of time it has been at work, and the type of wood it attacks. Some fungi attack many different kinds of wood, while others are limited in their choice. Owing to their less exacting moisture requirements, wood-destroying fungi are able to live on heartwood as well as sapwood. The fruiting bodies, usually quite large, are found on the surface in the form of brackets, crusts, or mushrooms or toadstools. They are not developed until the hyphæ have been at work for some time; consequently, the presence of fruiting bodies indicates serious decay.

Two types of wood-destroying fungi may be recognized, (1) those mainly attacking the heartwood, rarely the sapwood, of standing living trees, and (2) those principally confining their activities to the manufactured product, such as sawed lumber, crossties, and poles. The former type may continue their work of destruction after the tree has been cut down and worked up into lumber. The latter, attacking the manufactured product, usually invade the sapwood first, since it is far richer in stored food, generally has a higher moisture content than the heartwood, and is not so inherently resistant to decay. Fungi causing this type of decay are often very abundant in yards where the lumber is closely piled on damp earth, with little or no aeration under the piles, and much accumulated wood débris scattered throughout the yard. Unfortunately, such conditions are all too prevalent in mill yards. Sanitary yards both at the mills and the factories are badly needed. Humphrey (28) gives a complete account of the life history and habits of these fungi, the damage caused by them, and methods for their control.

CONDITIONS AFFECTING DECAY.

All conditions which favor sap stains are equally favorable to wood-destroying fungi. Furthermore, the latter can attack wood with a lower moisture content, so the fact that wood does not sap-stain is no indication that fungi causing decay may not be present. The discolorations caused by the latter in sapwood are not so pronounced as sap-stain; consequently, they are much harder to detect.

Moisture in wood.—Dry lumber will not decay. The most efficient method to prevent decay is to air-dry or kiln-dry lumber immediately and then keep it dry by proper methods of storage. Placing dry lumber in the open, exposed to rain, or in damp sheds can not be too strongly condemned. If the lumber becomes moist again, it is just

as liable to decay as before. To be sure, kiln drying is much better than air drying, since the high temperatures employed in the former process are probably fatal to the hyphæ of some decay-producing fungi, while under the latter conditions the fungi may merely remain dormant until suitable moisture conditions are again restored. However, since wood-destroying fungi are common around and in yards and wood-working factories, the chances are that kiln-dried lumber will be reinfected, and if it becomes moist again decay will begin.

Shipping green or even partially air-dried lumber on long voyages through tropical seas in the hold of a vessel offers a chance for a heavy loss through decay. The close humid air of the ship's hold becomes a perfect forcing chamber for wood-destroying fungi when warm latitudes are reached. Shipments of Douglas fir leaving the Pacific coast perfectly sound have contained a considerable percentage of decayed lumber when unloaded at a South African port (36, p. 36). Indirect reports indicate that the same condition resulted during the World War in some shipments of Sitka spruce routed to Europe through the Panama Canal and the Mediterranean Sea.

Durability of wood.—Resistance to decay, or as it is termed "durability," is a factor that should no longer be neglected in selecting woods for airplane construction. Airplanes are being more and more exposed to unfavorable weather conditions as their use extends, conditions which in some instances are highly favorable to decay. Furthermore, certain conditions created by the construction of an airplane promote decay. For example, in the interior of the wings the relative humidity may be much higher than that of the surrounding air, and there is often considerable condensation of moisture. In addition, the temperature is slightly higher. All these factors are favorable to the development of wood-destroying fungi.

Within any species durability increases with the increase in specific gravity. Consequently, the fact that only wood with high specific gravity is used for aircraft not only increases strength but serves to increase durability. However, it is well known that different species vary widely in their durability. Unfortunately, spruce is not at all durable. Neither are basswood and birch. Douglas fir is fairly durable, as is also white oak. But the cedars are remarkable for their inherent durability, and among these Port Orford cedar compares favorably with spruce in all its strength properties and is only slightly heavier. Consequently, this wood can not be too highly recommended for use in aircraft where resistance to decay must be considered. Sapwood must not be used under such circumstances, for no matter what the species is it decays easily.

Contrary to existing belief, the resin content of wood is of slight importance in relation to durability (74, p. 153-154; 75, p. 66-68). Resin itself has no poisonous effect on the growth of fungous hyphæ, and its only beneficial effect in increasing durability is its waterproofing action on wood. This is so slight, however, if the normal resin content of softwoods is considered, as to be practically negligible. If wood is rendered more durable through a sufficient increase in its resin content to have a decided waterproofing effect,

it is usually completely resin soaked or contains pitch streaks which make it unsuitable for painting or contact with fabric coverings.

INCIPIENT DECAY.

It is a simple matter to recognize well-advanced rot or typical decay. Here the changes in the wood structure due to the longer action of the wood-destroying fungus are so profound as to be very plainly apparent, but the earlier stages of decay, termed incipient decay, immature decay, or advance rot, are often far from easy to detect (6, 7). In some cases detection is practically impossible without a microscopical examination of the wood.

Specific gravity is not a reliable index of decay. It has been suggested that decay in any piece of wood will be immediately reflected in a lowering of the specific gravity. But this can not be detected unless the specific gravity of the piece was known before decay commenced, a manifest impossibility in most cases. Incipient decay does not cause a sufficient reduction in the specific gravity to bring the heavier pieces of wood below the minimum set for the species. The writer has tested pieces of yellow birch, white ash, and Douglas fir with conspicuous incipient decay and found the specific gravity of the affected pieces to be from 0.05 to 0.2 higher than the minimum permissible. The same condition will exist in all species. Douglas fir with pronounced white cellulose pockets characteristic of the final stage of red-rot or conk-rot has been found in some cases to have a higher specific gravity than the minimum of 0.45. Of course, when sound such wood had a high specific gravity.

Wood is weakened by incipient decay, the degree depending on the stage of the decay and somewhat on the species of fungus at work. Furthermore, if infected material is merely air dried the hyphæ may remain dormant, ready to continue their work of destruction again if suitable conditions arise. The chalky quinine fungus (*Fomes laricis* (Jacq.) Murr.), which normally causes decay in the heartwood of various coniferous trees, either living or dead, has been found causing decay in the roof timbers of cotton weave sheds (5). Undoubtedly this originated from timbers containing incipient decay of this species placed in the roofs at the time they were built, where the high temperature and humidity which prevails in such sheds soon resulted in renewed activity of the fungous hyphæ and their spread to adjoining sound timbers. The rose-colored *Fomes* (*Fomes roseus* (Alb. and Schw.) Cke.), which is common on dead trees and is sometimes found on living trees in the coniferous forests of the Pacific Northwest, has been found to be very destructive to timbers in basements with high humidity and poor ventilation in the Northeastern States (26, p. 28). As a general rule, infected wood must not be used.

It is extremely doubtful whether incipient decay in one of the laminations of ply wood can be considered an important defect. In the first place, the reduction in strength would be negligible. Furthermore, there would be but little danger of the fungus ever resuming its activities, because the high degree of heat and humidity to which the ply wood is subjected during various stages of its manufacture must kill the vegetating hyphæ. However, this does not prevent reinfection and subsequent damage if conditions for decay

again become suitable. Laminations with incipient decay should not be used in propellers. In this place the reduction in strength need not be so carefully considered as the variation from the normal shrinking and swelling that would result. Unequal and particularly unusual strains and stresses must be avoided above all things in propellers.

Incipient decay usually appears as a discoloration, in some cases pronounced, in others so faint as to be practically invisible. Most of this decay in airplane lumber was actually in the tree when it was cut or in the logs when they left the woods. It is rare that any serious effort is made in the woods or at the mills to cut out incipient decay. When the logs are bucked and sawed the typical decay is usually trimmed off, leaving the less apparent incipient decay in the lumber. After sawing, the upper grades of lumber, which include airplane stock, are usually handled carefully enough at the larger mills to prevent further damage.

When decay commences in a living tree, it spreads upward in the heartwood if the infection entered at the butt, or in both directions if it occurred higher on the trunk. Very rarely do the decays in the heartwood of living trees attack the sapwood. Beyond the typical decay, that is, where the wood is decidedly rotted, extend the incipient stages of decay, which become less and less apparent as the distance from the typical decay increases. Finally, the incipient decay ends entirely. The wood beyond is then sound. The incipient decay rarely ends abruptly or evenly, but usually fades out in one or more irregular streaks, which may be short or long. It usually extends only 3 or 4 feet longitudinally beyond the typical decay, but with certain wood-destroying fungi on some hosts the incipient decay may extend 15 feet or more in advance of the typical decay. Furthermore, the latter is always bounded radially by incipient decay, and this boundary is often irregular. Boards sawed from diseased trees may contain all stages of decay or incipient decay, occupying part or all of the board. The fact that the fungi causing decay in standing trees may continue their work of destruction in logs in the woods, or even in sawed lumber if conditions are favorable, indicates the necessity for having logs removed from the woods, sawed, and the lumber dried with reasonable promptness.

When lumber is green the discolorations indicating incipient decay are more intense than when the wood has seasoned for some time. During the drying process the discolorations fade in varying degrees. Furthermore, if a new discoloration appears within one or two weeks after the lumber comes from the saw it is practically certain that it is not caused by one of the wood-destroying fungi attacking the piled lumber, since the latter work more slowly. A sap-staining fungus or a chemical reaction is the most likely agent in such a case.

Incipient decay should be detected and eliminated before the lumber is worked into individual parts. If the entire piece is not defective the sound portion can be sawed out and utilized. In marking a piece for cutting, however, it must be remembered that decay extends more rapidly with the grain in a tree or piece of wood than it does across the grain; thus, to be perfectly safe, an allowance of 2 feet should be made in the direction of the grain beyond

the last visible evidence of incipient decay, while across the grain an allowance of 2 to 3 inches will suffice.

TYPES OF DECAY IN LIVING SOFTWOOD TREES.

One of the most common decays in airplane lumber is that caused by the ring-scale fungus (*Trametes pini* (Brot.) Fr.) in the heartwood of living trees. It may occur in practically any species of softwood, but is very common in Douglas fir, spruce, and pine. The decay, known under various common names, such as red-rot, red-heart, conk-rot, white honeycomb rot, pecky wood-rot, and ring-scale rot, is readily recognizable in its typical stage by the fact that the heartwood is honeycombed with small white pits in which the wood is reduced to a soft fibrous mass of cellulose (in a chemical sense cotton is practically pure cellulose), these pits being separated by firm and apparently sound wood. Plate II shows typical decay in Douglas fir.

While the typical decay is closely similar in appearance in various species of wood, there is considerable difference in the incipient decay. In Douglas fir as a general rule it appears as a pronounced reddish purple or olive-purple discoloration, gradually tapering and becoming fainter until it is lost entirely. The color is often most pronounced in the outermost heartwood just where it joins the sapwood. In some cases it appears brownish against the red or yellow heartwood. At the lower limits of the incipient decay, where it begins to merge into typical decay, a close scrutiny will usually reveal faint indications of the cellulose pits. Vertically the discoloration may extend 10 feet or more in advance of the cellulose pits, but radially this is limited to 2 or 3 inches. The discolorations described are often bounded by a narrow zone of pronounced red color. Plate III shows discoloration in Douglas fir with the formation of cellulose pits beginning. In rare instances the first indication of the decay may be the tiny golden white spots or streaks which indicate the initial stage in the formation of cellulose pits. In this case the discoloration is probably too faint to be recognized, and material of this kind is quite easily overlooked.

In white and red spruce (55, p. 32) this incipient decay first appears as a change in color from the pale yellowish or reddish brown of the normal heartwood to a light purplish gray, which deepens to a reddish brown, with the gray forming the outer boundary of the reddish brown discolored portions. Next, the cellulose pits appear, visible at first as very tiny black lines following the grain of the wood, but soon revealing their true nature. The discoloration is not so pronounced as in Douglas fir. In Sitka spruce the tiny black lines preceding the cellulose pits are not found.

The yellow pines first show the decay by a pronounced pink color which rapidly gives way to a red-brown; hence the names red-rot and red-heart. During this stage the wood is hard and firm. Then the white pits develop, although in some cases they appear so sparingly that they are readily overlooked.

In certain woods there is little or no discoloration with this incipient decay. This is true with incense cedar, Port Orford cedar, and western red cedar, and is probably the same with other cedars. The first indication of the diseased condition of the wood is the appear-

ance of cellulose pits. Hence, the purplish red color commonly found in the heartwood of incense cedar (see p. 16) and western red cedar need not be mistaken for decay.

As yet very little is known in regard to the reduction in strength due to incipient decay caused by the ring-scale fungus. However, it seems probable that such reduction is slight until the appearance of the white cellulose pits; but it is to be remembered that pieces with discoloration contain hyphæ which may again attack the wood, if suitable conditions arise. Consequently, stock with any stage of this decay should not be used.

The chalky quinine fungus causes a pronounced decay in the heartwood of many softwoods. The typical decay is a brownish red friable crumbly mass, often with conspicuous mycelium felts filling the cracks. This is shown in Plate IV. The incipient decay is very difficult to detect, as a rule. Even when the wood has been severely weakened the extremely faint brownish discoloration is not discernible to any but the most expert eye. However, the incipient stage of this decay in western yellow pine appears as a red-brown or pronounced brown discoloration in the pale-lemon to light orange-brown heartwood. The discoloration is not uniform over the entire affected portion, but may occur on the radial or tangential face in broad bands of varying intensity or even intermingled with narrow bands of the normal light-colored heartwood. In cross section the infected wood presents a mottled appearance. The horizontal limits of the discoloration are bounded by a narrow band of pronounced pink or red. At the upper limits of the incipient decay the discoloration becomes fainter until it finally disappears. The discolored wood seems to be hard, firm, and strong, but in reality it is seriously weakened. Plate V illustrates this condition.

The typical decay caused by the sulphur fungus (*Polyporus sulfureus* (Bul.) Fr.) is very similar to the foregoing. However, it is not confined to softwoods. It is common only in the true firs among the softwoods, but is very prevalent among the hardwoods, particularly the oaks. The heartwood of living and dead trees is affected. The incipient decay is difficult to detect, being first indicated by a faint brownish discoloration.

The velvet-top fungus (*Polyporus schweinitzii* Fr.) also causes a reddish brown friable rot, which is, however, confined to the butt and roots of the tree. The mycelium felts are very fine and inconspicuous. Only softwoods are affected. Normally the incipient decay is very difficult to detect. It first becomes evident in Sitka spruce⁶ as pale-yellow to lemon-yellow streaks or spires extending longitudinally beyond the light yellowish to reddish brown discoloration which characterizes the more visible incipient decay. In the latter stage a softening of the wood is apparent. In Douglas fir the incipient decay is first evident as a faint yellowing or browning of the normal heartwood. This or an exactly similar decay in western red cedar is first indicated by a decided deepening in the color of the normal brownish heartwood. The discolored zone often extends horizontally for several inches around the typical decay and for a foot or more in advance of it. The discoloration may be confused with the normal

⁶ The description of the decay in this species caused by *Polyporus schweinitzii* is based on notes furnished to the writer through the courtesy of E. E. Hubert.

darker colored bands of heartwood which are found in some trees, but such bands are confined to a definite group of annual rings.

Redwood is subject to a brown friable decay which is not confined to the butt of the tree. The fungus causing this is unknown (57). The first indication of the incipient decay is a very faint light brownish discoloration on the light-cherry to deep reddish brown heartwood. This is most readily detected on the tangential face in the summer wood. When the brownish discoloration is plainly apparent, the decay has progressed so far that the affected wood feels softer than the normal to the thumb-nail. The typical decay is dark brown in color, very soft, and easily crumbled. Thin crustlike mycelium felts occur along the sides of the cracks.

These reddish brown or brown friable decays which are so difficult to detect in their incipient stages, particularly in woods with a pronounced reddish or brownish heartwood, reduce the strength of the wood far more seriously than incipient decays of the red-rot type; in fact, the wood may be weakened before the incipient decay is visible. Consequently, in cutting out such decays from lumber it is advisable to leave a margin of safety of at least 2 feet in a longitudinal direction beyond the last visible evidence of the incipient stage.

Incense cedar is very commonly decayed by the incense-cedar dry-rot fungus (*Polyporus amarus* Hedge.). The typical decay consists of vertically elongated pockets, varying in length from half an inch to about a foot, which are filled with a brown friable mass, and the line of demarcation between the sound and decayed wood is very sharp. In some of these pockets small cobweblike or feltlike masses of white mycelium occur. The pockets are separated from each other by what appears to be sound wood, although in some cases streaks of straw-colored or brownish wood may extend vertically between two pockets. This is especially noticeable between young pockets. The pockets of incipient decay are at first firm and very faintly yellowish brown. This color deepens slightly, and the wood becomes somewhat soft. The incipient decay extends but a short distance vertically in advance of the typical decay, and a distance of 2 feet beyond the last visible evidence will usually exclude all decay. The incipient decay is only faintly apparent, occurring as it does in pockets with the color in the very earliest stages differing but slightly, when at all, from the normal wood. The fact that an occasional pocket may be found several feet in advance of the main body of decay makes this decay an exceedingly dangerous one. The wood, even in an incipient pocket is decidedly weakened (although the intervening wood is apparently not affected), and this makes a weak spot that is hard to detect. Such cases are fortunately not common, and the fact that most incense-cedar stands are so badly decayed will probably preclude this species from any extensive use for airplane construction. Other woods are subject to similar decays. That found occasionally in western red cedar may be caused by the same fungus, while "peckiness" of bald cypress (*Taxodium distichum* (Linn.) Rich.) results (33) from the work of a different organism (*Fomes geotropus* Cke.).

One of the most striking discolorations indicating decay and at the same time one of the most serious incipient decays is that caused

by the Indian paint fungus (*Echinodontium tinctorium* E. and E.). This is found on the true firs in the western United States, being especially prevalent and severe on white fir (37). It is also exceedingly serious on western hemlock (71).

In white fir the first indications of this decay on a radial or tangential section are light-brown or golden tan spots or larger areas of discoloration in the light-colored heartwood, which may be accompanied by small but clearly distinct radial burrows, resembling somewhat very shallow insect burrows without the deposit of excrement. These burrows are not easily detected in cross section. Next, rusty reddish streaks appear following the grain. Throughout this stage the wood appears firm and strong, but in reality is so greatly weakened that boards may separate along the annual rings when dried. The discoloration intensifies, the wood becomes soft, showing a decided tendency to separate along the spring wood in the annual rings, and finally the typical stage is reached, in which the wood is brown, with pronounced rusty, reddish streaks and becomes fibrous and stringy. Hence, the name stringy brown-rot is applied to the decay. The incipient decay usually extends from 2 to 6 feet beyond the typical decay. Plate VI shows the incipient decay.

In western hemlock the incipient decay is much harder to detect, because the initial discoloration above described so closely approximates the pale-brown, slightly tinged with red, color of the normal heartwood. The wood first assumes a faint yellowish color, which is sometimes intensified by the presence of small, hardly discernible brownish areas. These areas later develop into the typical decay. The extension of the incipient decay beyond the typical decay varies from 1 to 5 feet. For the sake of safety 2 feet should be added beyond the last recognizable yellowish discoloration in order to eliminate all incipient decay.

TYPES OF DECAY IN LIVING HARDWOOD TREES.

Hardwood trees are subject to very serious decays. One of the most important from our standpoint is the white heartwood rot (58) so commonly found in commercial white-ash stock, caused by the ash Fomes (*Fomes fraxinophilus* (Pk.) Sacc.). This fungus attacks the heartwood of living trees and produces a very characteristic rot. On cross section the first indication of the decay is a light brownish discoloration, often difficult to distinguish from the normal grayish brown or reddish brown heartwood. This discoloration is most apparent in the broad bands of summer wood. Next, there is a bleaching of the spring wood, during which it turns to a straw color, and then small white spots or specks appear. On the radial (edge-grain) and tangential (slash-grain) faces these appear as small whitish spots, streaks, or blotches, usually following the grain, but some may be at right angles to it if the decay follows a medullary ray. The whitish color becomes more marked, until the entire spring wood is affected and appears disintegrated. Then the fibers fall apart. The summer wood passes through the same process, but much more slowly, thus during the earlier stages of the typical decay causing a banded appearance. The completely rotted wood is whitish or straw colored, very soft, and spongy, readily absorbing water. A section

from a white-ash longeron with this incipient decay is illustrated in Plate I, right side.

Apparently mycelium does not occur in the brown discolored wood in advance of the white spots. It would seem that the wood is not weakened until the white spots are found, and the wood with the brown discoloration alone need not be rejected. It is an excellent hint for close scrutiny of an affected piece, however. The incipient decay is somewhat obscured in rough lumber, but is usually readily apparent on smooth surfaces. This stage does not extend many feet beyond the typical decay, and on long boards the latter will most likely also occur. Once the presence of the typical decay is ascertained it is a relatively simple matter to determine the limits of the incipient stage.

Areas in which the wood failed to change color upon transition from heartwood to sapwood (see p. 16) can be differentiated from the initial stages of white-rot by their larger size, by the straw-yellow color as opposed to the whitish of the decay, by the sharp line between the two colors, and by the fact that the spots are much larger, without becoming soft and spongy, than would be the case with the decay.

Sweet birch and yellow birch are subject to a white heart-rot (32) which, although very similar to the foregoing, is caused by a different fungus, the false tinder fungus (*Fomes igniarius* (L.) Gill.). The first indication of the incipient decay is a brown discoloration, not very apparent against the reddish brown heartwood. Next, faintly paler streaks or spots appear, which finally become a yellowish white, strikingly apparent against the dark background. This stage is illustrated by Plate VII. In the center of these streaks small spots are found in which the yellowish white wood appears to have collapsed. Usually the long axis of these spots is parallel to the grain, but in some it may be at right angles to it. The wood up to this time appears firm and hard. Next the white streaks merge, the wood becomes soft, and finally the entire affected portion of the heartwood is reduced to a yellowish white fibrous mass composed principally of cellulose, the result of the delignification by the fungous hyphæ. As in the white-rot of ash, hyphæ are not found in the brown discoloration. Hence, no reduction in the strength of the wood may be expected until the very first indications of the whitish streaks or spot, which may be found as much as 8 feet in advance of the typical decay.

One of the most common decays (24) on oaks and also on certain poplars (*Populus*) is the heart-rot caused by the oak fungus (*Polyporus dryophilus* Berk.). The incipient decay of this whitish piped rot in white oak has a water-soaked appearance in the unseasoned wood, but when dry the discoloration becomes hazel to tawny in color. The discoloration may extend from 1 to 10 feet in advance of any other indication of the decay. The next stage of the decay, which is best seen on a radial face, is characterized by whitish spots or streaks, usually following the medullary rays, which produce a mottled appearance of the wood. This mottling is the result of a delignification process; that is, the lignin is removed from the wood, leaving only the cellulose. In the final stages the decayed wood is firm, with a white, stringy appearance, and the delignification is practically complete.

A somewhat similar rot in oaks (34) is the honeycomb heart-rot (*Stereum subpileatum* B. and C.). As in the whitish piped rot, the first indication of this decay in white oak is a slight water-soaked appearance of the fresh heartwood, and when dry this "soak" becomes a tawny color. Next, light-colored isolated areas appear in the tawny discolored wood, and pronounced delignification occurs. This is indicated by the appearance of very small irregular whitish patches in the light-colored areas. These patches develop into small pits with their long axes parallel to the grain of the wood, and they increase in number until the affected wood is completely occupied. The pits are from one thirty-second to one-fourth of an inch wide by one-fourth to five-eighths of an inch long, and lined with cellulose fibers. At this stage the appearance of the decay is similar to the red-rot in softwoods previously described. Later the cellulose lining may disappear. The wood is probably not weakened by this decay until the light-colored areas appear in the tawny discoloration.

An incipient decay is sometimes encountered in African mahogany, the cause of which is unknown to the writer. This decay appears as light-yellow, brown, or merely lighter brown closely crowded spots or flecks on the reddish-brown heartwood. These flecks vary from one-sixteenth to one-quarter of an inch long and are several times longer than broad, the long axis corresponding with the direction of the grain in the wood. Such wood is weakened.

TYPES OF DECAY IN LOGS AND LUMBER.

In addition to the wood-destroying fungi which normally attack living trees, and which may continue to decay the wood after the tree is cut, there are fungi which grow only or principally on wood in the form of logs or lumber. Owing to their destructiveness, some of these deserve more than passing mention. Although it is true that damage caused by such fungi is due to improper handling of the timber during the course of manufacture and utilization, unfortunately such improper handling does occur and must be reckoned with.

Softwood logs and lumber.—One of the most important of these fungi is that which causes dry-rot in stored logs or lumber and in timber in structures (22). The term "dry-rot" is loosely applied to cover almost any type of decay, but it is correctly applicable only to the work of the dry-rot fungus (*Merulius lacrymans* (Wulf.) Fr.). This decay is more common on coniferous woods than on hardwoods. The incipient decay appears as a yellow-brown discoloration not easy to detect. Wood with typical decay is yellow to brown in color, much shrunken and cracked, and is so badly disintegrated that it can be easily crushed to a powder. Both sapwood and heartwood are attacked.

Another common decay on logs and sawed lumber, particularly on railroad ties, is the brown-rot (62) caused by the brown Lenzites (*Lenzites sepiaria* (Wulf.) Fr.), which is practically confined to coniferous wood. The typical decay is brown, friable, and easily reducible to a powder. In the early stages of decay infected wood is darker in color than the normal. Sometimes the early spring wood of the annual rings may be completely decayed, while the

summer wood is scarcely affected. In this condition the wood separates readily along the annual rings.

Hardwood logs and lumber.—Certain fungi (*Polystictus versicolor* (L.) Fr., *Stereum hirsutum* (Willd.) Pers., and others) cause a sap rot very difficult of detection in its incipient stage. The typical decay is very light in weight, white in color, rather soft, and easily broken in the hands. But since the first indication of this decay is a faint whitening of the diseased wood and white is the normal color of most sapwoods, it is apparent that the initial stages may be readily overlooked. At the same time the wood is decidedly reduced in strength. The decay is most common on hardwoods, but also occurs to some extent on softwoods. Fortunately none of the fungi causing this white sap-rot attack living trees of the species which furnish airplane timber.

Red-gum logs when left in the woods for any considerable time are subject to a very serious sap-rot (59) caused by the smoky *Polyporus* (*Polyporus adustus* (Willd.) Fr.). The heartwood is comparatively durable. Boards cut from diseased logs are very characteristic and striking in appearance. Normally, red-gum sapwood is a light yellowish white, commonly with a reddish tinge. The sapwood in a decayed board has a number of various-colored streaks or lines irregularly distributed from the end of the board toward the middle. These streaks are light orange at first, but in the more advanced decay are a very light straw color (in fact, almost white) and are intermingled with lines and patches of bluish gray and the normal-colored sapwood. Black zigzag lines may extend from the ends of the board for a distance of 2 inches or more parallel to the grain. The general consistency of sapwood with this incipient decay, which may extend 2 or 3 feet in advance of the typical decay, is firm and solid. Sapwood with the typical decay is badly broken down, being soft and pulpy and without firmness.

This and other sap rots may be prevented by shortening the drying period in the woods. Coating the ends with hot coal-tar creosote immediately after the logs are cut is also effective. Where possible, all freshly cut logs, particularly those cut during the spring and summer, when the rot develops best, should be peeled. Sap rots similar to those found in the red gum are found in tupelo gum (*Nyssa sylvatica* Marsh.) and in maple.

DECAY IN FINISHED AIRPLANES.

Little information about decay in finished airplanes is available. In the past there has been very small chance for airplanes to decay, because the completed machines rarely ever were stored, and their life in use was a relatively brief one; but since the conclusion of the World War immense quantities of airplane material have been placed in storage, and the average life of the machines has been materially increased by changes in construction. Under average conditions there should be practically no damage to finished airplanes by decay. When in use there is little danger from this source, owing to the fact that when not actually in flight the machines are properly housed. The wooden parts in the interior of the wings and around the engine are most susceptible. In these places there is an increased temperature and relative humidity. Keeping the machines in a dry

place when not in use will suffice in most climates. There is more danger in humid tropical or semitropical regions, particularly to seaplanes.

Serious loss can easily result to machines through improper handling while being stored or shipped. Airplanes are usually knocked down for storing and shipping; that is, the machine is taken apart, and the individual assemblies, such as the wings, tail surfaces, and fuselage, are handled separately. When shipped, these parts are carefully wrapped in heavy paper and packed in solid crates. If these crates are left out in the air, cracks open up between the boards, water may get in, and then the trouble commences. Once damp, it is almost impossible for the mass of paper wrappings to dry out unless the crate is completely unpacked. Varnish or dope does not prevent the taking up of moisture, so that the wood soon attains a moisture content sufficient for the growth of molds and wood-destroying fungi, while the other conditions within the crate, such as lack of air circulation with the resulting high humidity and the higher temperatures, are ideal for the development of these organisms. Even before the wood is decayed the elements of the ply wood are very likely to separate, owing to the action of moisture and molds on the glue. Even water-resistant glues can not permanently withstand such conditions.

There is no cure for decay, once it has started. The damaged part can be replaced and further destruction prevented, but the constant aim should be not to let decay begin. Material should not be kept in packing cases any longer than is necessary. The practice of leaving packing cases containing airplanes or spare parts in the open for several months can not be too severely condemned.

When put in storage, the parts should be removed from the cases and placed on racks, so that a complete circulation of air is possible around each unit or piece. The storage houses should be equipped with a forced-ventilation system, so that air of the proper humidity can be constantly circulated through the piles of material. The relative humidity should be maintained at 60 which will keep the wood at a moisture content of about 11 per cent, low enough to prevent decay, mold, or sap-stain.

Circumstances will arise where planes are in use or while being shipped when it will be impossible to maintain proper conditions to prevent deterioration. In the warm climate and high humidity of tropical or semitropical regions in particular this will be true. It is advisable to have planes for use under such conditions constructed from a durable wood such as Port Orford cedar. Where this can not be done, methods should be employed to make the other species more durable.

Wood may be moisture-proofed by the application of aluminum leaf. This not only prevents decay, since the wood is kept dry, but protects the glue joints from the action of moisture and mold.

As a last resort, the wood could be treated with preservatives to prevent decay. These liquids are most effective when forced into the wood under pressure. Consequently the completed individual wood parts would have to be treated before assembly. Sodium fluorid could be used on parts to be glued, while coal-tar creosote could be applied to the others. The most highly efficient of all,

mercuric chlorid, is unfortunately a deadly poison, corrodes metal, and is very difficult to handle. The subject of preservative treatment is one about which little is known as applied to airplanes.

Little information is available as to what fungi actually cause decay in finished airplanes or as to the types of decay found. Undoubtedly the fungi most concerned are those commonly attacking the manufactured product, such as the dry-rot fungus, the brown Lenzites, or the rose-colored Fomes. Fungi decaying the heartwood of living trees are not commonly found. When they do appear, this is practically proof positive that the manufacturer used wood with incipient decay in the fabrication of the wooden parts.

SUMMARY.

Among the softwoods or conifers the most valuable for airplane construction are red, white, and Sitka spruce, the last being most important on account of its large size and the consequently greater proportion of clear lumber that can be obtained. A splendid substitute for spruce, and its superior where durability must be considered, is Port Orford cedar. However, the supply of this wood is limited. Douglas fir, which is much heavier than spruce and therefore not so desirable, is also extensively used. In those parts of an airplane frame requiring great strength and toughness, hardwoods are used. White ash is best, but white oak, hard maple, and rock elm may be substituted. Hickory is principally used for tail skids. Black walnut and true mahogany are unsurpassed for propellers, but yellow birch, sweet birch, African mahogany, black cherry, hard maple, and white oak are acceptable substitutes. As the supply of timber diminishes in the future, a wider variety of woods will be acceptable for airplane construction.

All wood is subject to defects, of which one of the most serious is decay; but other defects which reduce the strength of timber must be recognized. Among these can be mentioned spiral and diagonal grain, specific gravity that is too low or too high, brashness caused by excessive temperatures during steaming or kiln drying, compression failures, shakes, pitch pockets, and insect galleries.

Decay in its incipient stage is often not readily recognized; but wood with incipient decay must not be used in airplane construction, since infected wood may be reduced in strength. Furthermore, the decay may continue if suitable conditions arise. The first indication of decay is usually a discoloration of the infected wood, but not all discolorations result from decay. Marked discoloration of the wood, particularly the sapwood, usually accompanies pith-ray flecks and wounds made by lightning and sapsuckers. Conditions favorable for decay also promote sap stains. These discolorations of the green sapwood of various softwoods and hardwoods occur in two ways: (1) By an oxidation of the organic compounds in the cells of the sapwood when exposed to the air and (2) by the attack of sap-staining fungi, the hyphæ of which feed on the organic compounds in the cells of the sapwood without attacking the cell walls except to a negligible extent. The discolorations are confined to the sapwood as a rule, but occasionally the sap-staining fungi, may discolor the heartwood slightly. For practical purposes wood so discolored is not reduced in strength.

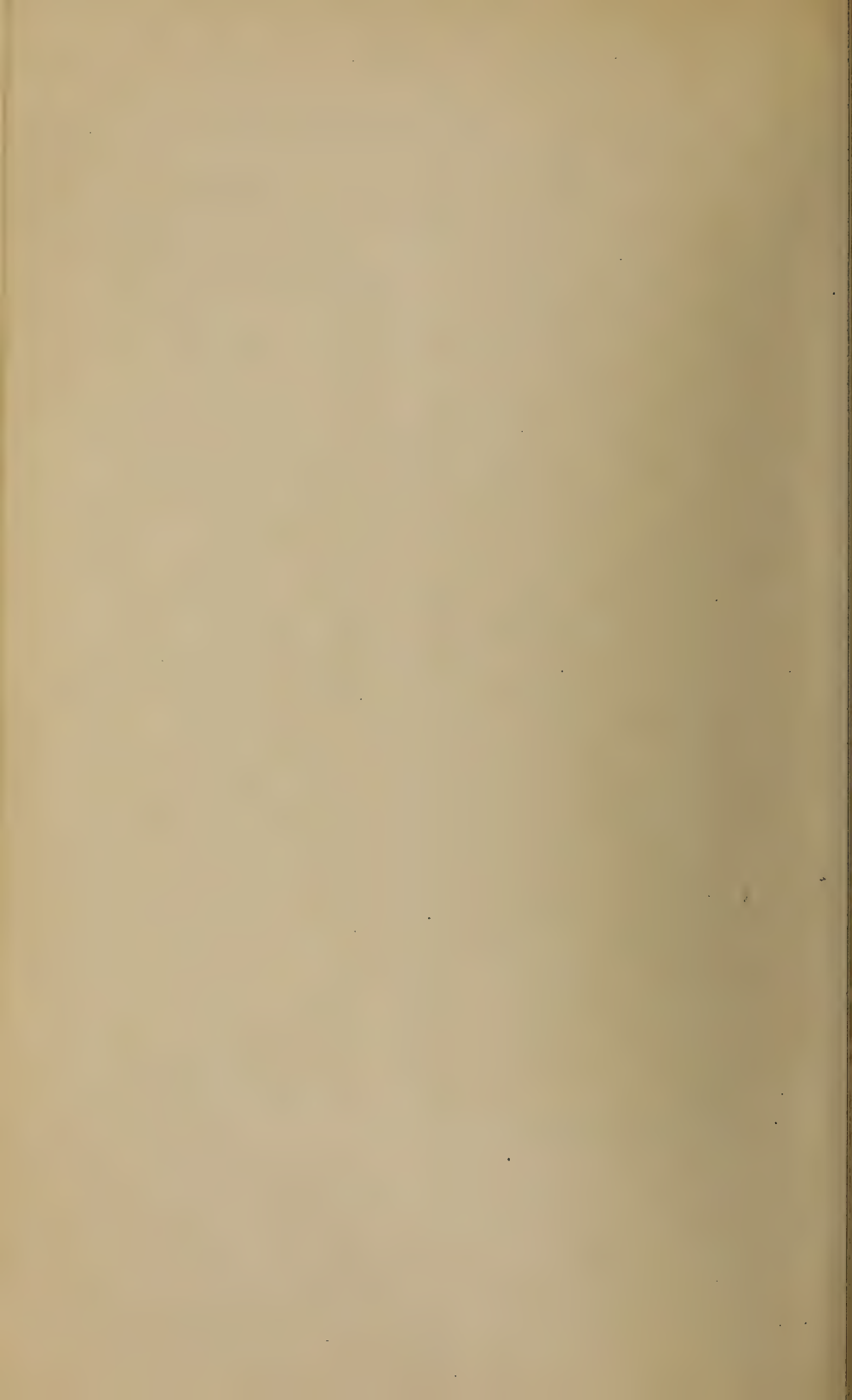
The discolorations resulting from incipient decay may be found in the sapwood or heartwood. Incipient decay extends for varying distances beyond the typical decay. In cutting out this defect it is advisable to leave a margin of safety of at least 2 feet in a longitudinal direction beyond the last visible evidences of the incipient decay, in order to remove all infected wood. This margin of safety is particularly important with brown or red-brown friable decays, since infected wood may be dangerously weakened by them while the incipient stage is still practically invisible.

Many decays other than those described in this paper are found in living trees, in logs, and in manufactured timber, but the examples cited include both the most important decays and the principal types. For most purposes it is sufficient to recognize incipient decay as distinguished from other discolorations or defects without determining the causal fungus.



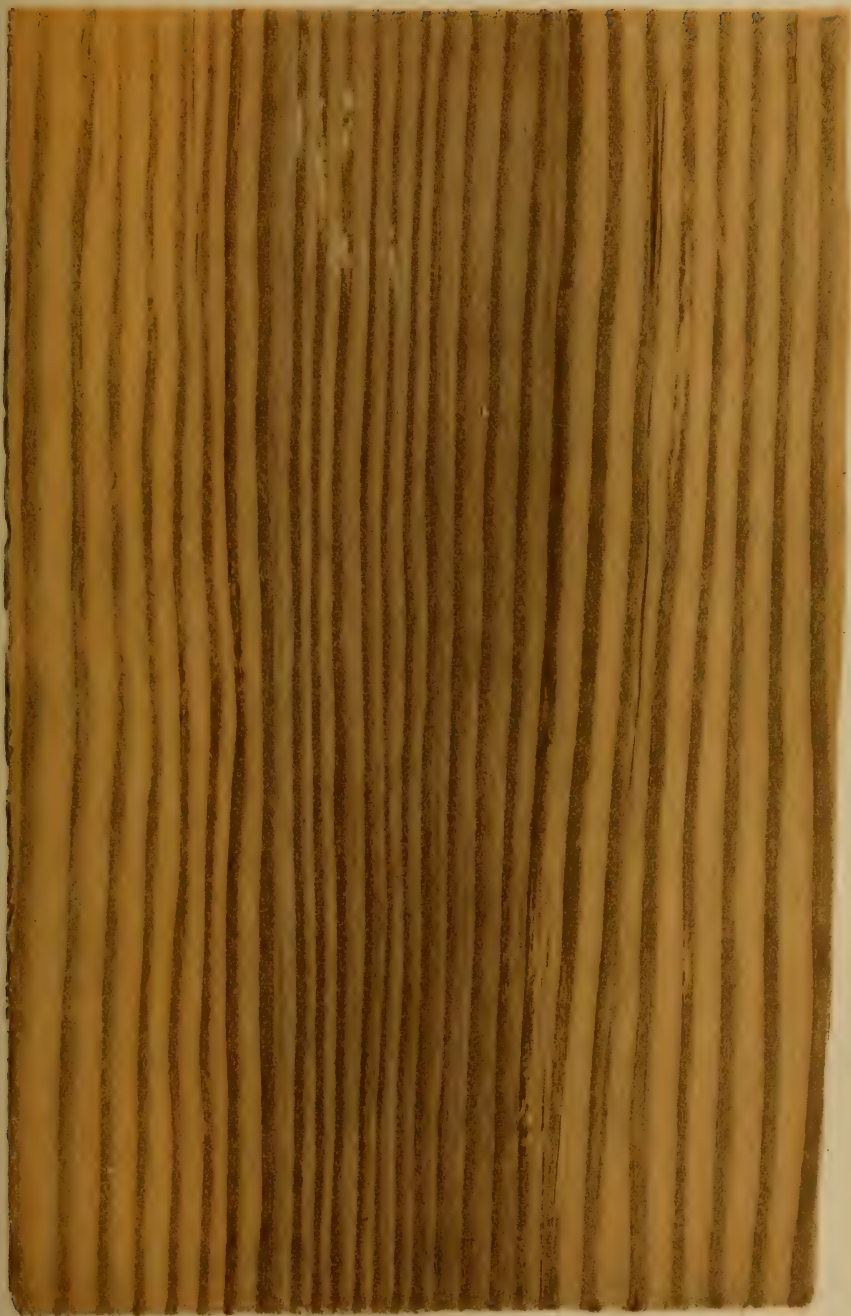
FIG. 1.—SECTION FROM A RIB WEB, SHOWING BLUE-STAIN IN SUGAR PINE.
The dark-blue specks are the ends of the medullary rays. The pale orange colored wood at the right is unstained heartwood.

FIG. 2.—SECTION FROM A WHITE-ASH LONGERON.
The brownish discoloration with the small white streaks indicates incipient white heartwood rot.





SECTION OF THE HEARTWOOD OF DOUGLAS FIR.
The typical decay here shown is caused by the ring-scale fungus. The light-colored
wood at the right is sound sapwood.



INCIPIENT DECAY IN DOUGLAS FIR CAUSED BY THE RING-SCALE FUNGUS.
The white spots are the beginning of the formation of cellulose pits in the central discolored zone, indicating decay.



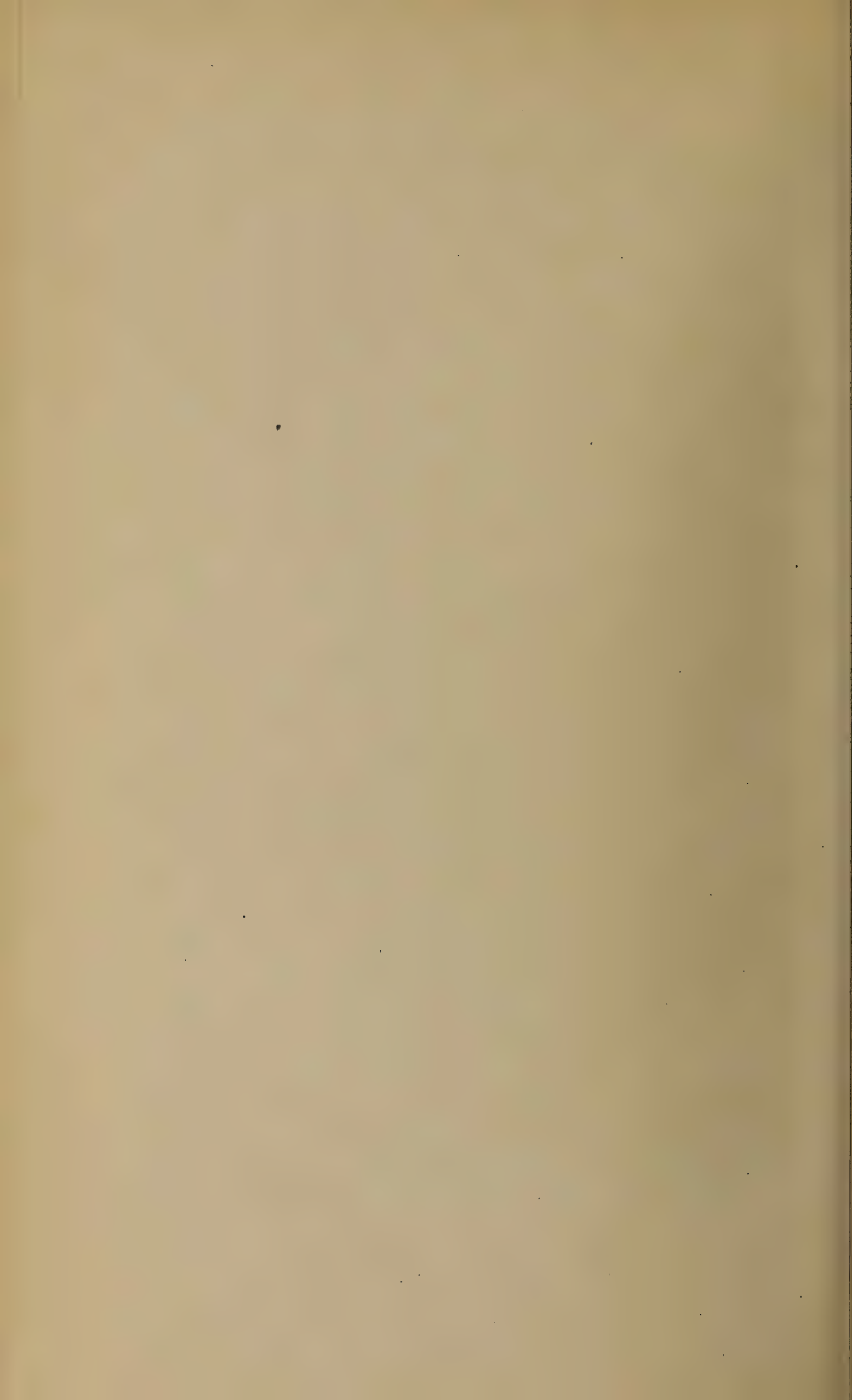
DECAY COMMON IN THE HEARTWOOD OF PINE, LARCH, AND DOUGLAS FIR.
This typical decay, with the characteristic conspicuous white mycelium felts, is caused by
the chalky quinine fungus.



INCIPIENT DECAY IN THE HEARTWOOD OF WESTERN YELLOW PINE.

The discoloration indicates the presence of decay caused by the chalky quinine fungus.

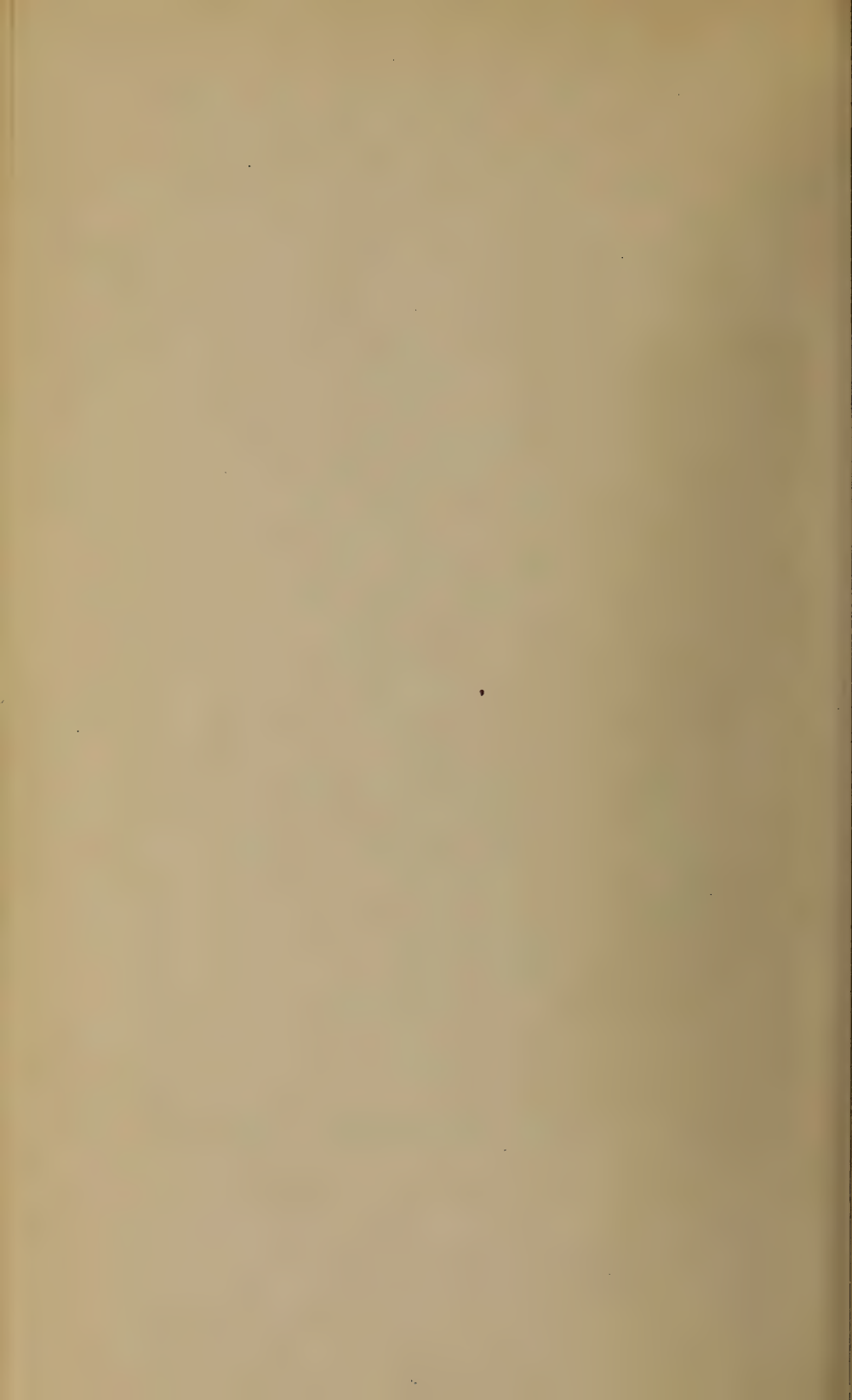
The pale orange colored wood at the right is sound heartwood.





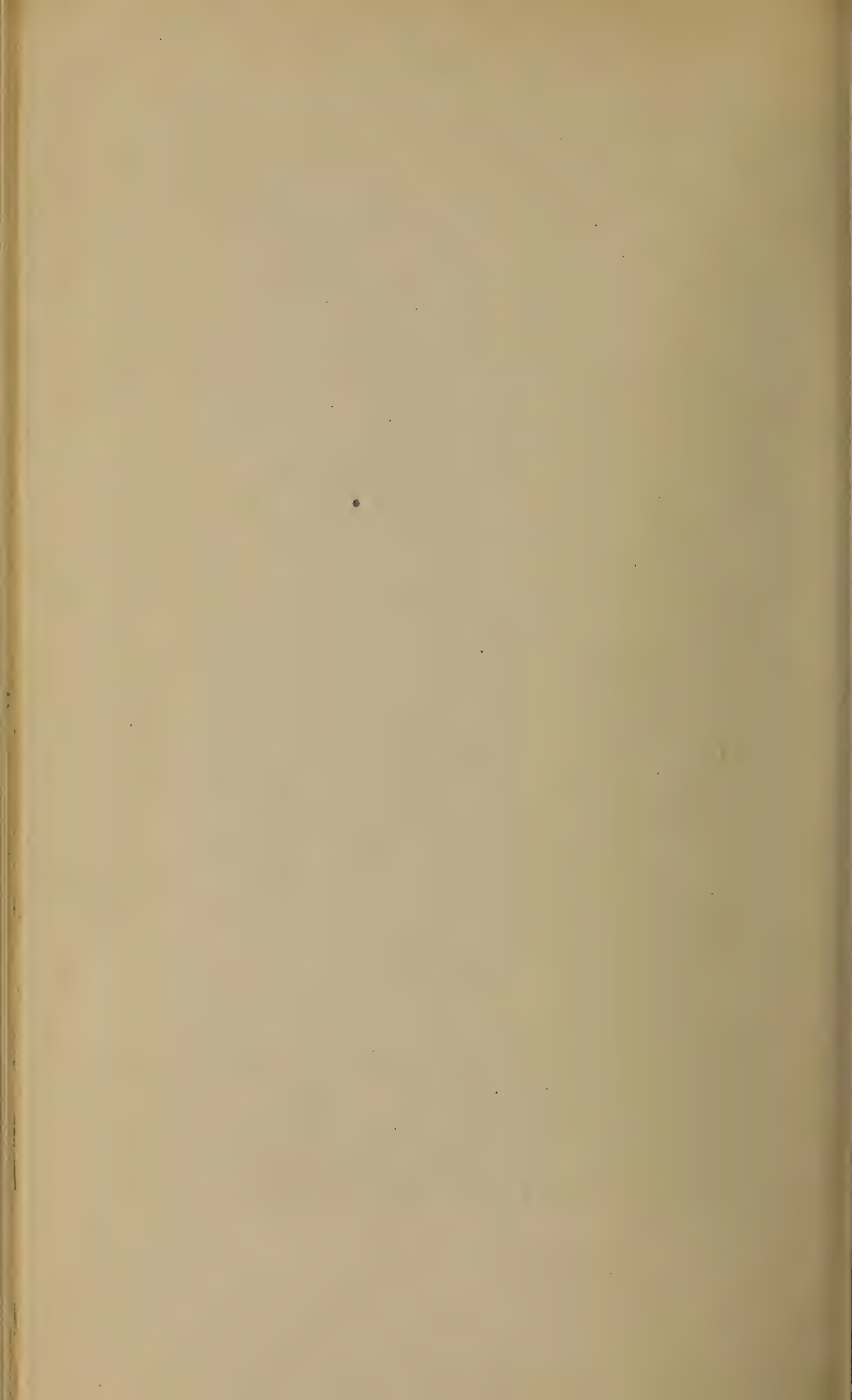
INCIPIENT DECAY IN THE HEARTWOOD OF WHITE FIR.

This golden brown discoloration indicates decay caused by the Indian-paint fungus. Note the contrast in color with the normal white wood.





SECTION OF YELLOW-BIRCH PROPELLER STOCK.
The incipient decay here shown is caused by the false tinder fungus.



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THE FORMATION AND PATHOLOGICAL ANATOMY OF FROST RINGS IN CONIFERS INJURED BY LATE FROSTS.

By ARTHUR S. RHOADS, formerly *Assistant in Forest Pathology, Office of
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INTRODUCTION.

Various writers have shown that an abnormal or pathologic parenchyma tissue may occur as an interruption of the normal course of the wood elements in the growth rings of coniferous trees, resulting from a variety of widely different causes, which may either directly or indirectly influence the growth of the cambium. Among these causes may be enumerated mechanical injuries of any kind; attacks by various cryptogamic and phanerogamic parasites which stimulate the woody tissue to an abnormal development; abnormal physiological conditions of growth and nutrition which per se produce a like effect; premature defoliation; and injuries resulting from such meteorological causes as lightning, frost, and drought. The last-mentioned three forms of injury have rather distinctive anatomical characteristics which are scarcely recognized in this country and additional knowledge of these is highly desirable.

Owing to its close resemblance to the disturbances in the wood caused by certain forms of lightning injury which he was studying, the writer was impelled to investigate also the pathological anatomy of late-frost injury. The present bulletin is therefore designed as a contribution to our knowledge of the pathological anatomy of late-frost injury in the conifers.

The material used as a basis of this study was collected by the writer in connection with his field work in various parts of northern Idaho, northeastern Washington, and northwestern Montana and was supplemented by material collected later in the District of Columbia and in Missouri. The photomicrographs were made by the writer from his own sectional preparations.

REVIEW OF THE LITERATURE.

Despite the great mass of literature on the subject of frost injury, there are but few descriptions of the pathological effect of the injury on the structure of the wood. In fact, the effect on forest growth of temperatures below the freezing point, or frost, is seldom considered, except in so far as it causes injuries the external manifestations of which are readily apparent.

The so-called frost rings, or "moon rings," as they sometimes are called when extending only a part of the way around the stem, occurring in young trees as a result of the action of frost, have been mentioned by various European writers, but it is only rarely that their structure and origin have been studied from the standpoint of their pathological anatomy, and illustrations of this abnormality are rare.

Mayr (5, p. 36)¹ states that the stimulating action of a mild late frost on the annual ring already in a state of cambial activity exerts itself in such a way that in place of the elongated tracheids a short-celled parenchyma arises. According to Mayr (5, p. 37), this abnormal wood may occur either on only one side of the stem or extend entirely around it, depending upon the way in which the cold air strikes the plant. In either case internal healing ensues, proceeding from the parenchyma cells of the wood, which fill up possible cavities with wound parenchyma, while a new cambium is developed in the bark from the bast parenchyma remaining alive. In addition, Mayr states that if the frost has killed the bast together with the cambial layer, then the entire plant part dies.

Hartig (2) investigated the action of a May frost on the shoots of young trees of *Pinus sylvestris*. He describes in detail the formation of zones of parenchyma tissue, which constitute the so-called frost ring, in the growth ring developing during the year of the injury. He likewise describes the peculiar permanent distortion of the injured young shoots, a circumstance occasioned by their loss of turgor and consequent drooping after the freezing, followed by an effort to redirect their shoots upward. In many cases, however, the whorls of shoots were killed outright.

Hartig also investigated the formation of similar frost rings in young trees of *Picea excelsa*, *Larix europaea*, and *Chamaecyparis lawsoniana*, but he illustrates their formation only in *Pinus sylvestris* and *Picea excelsa*. He states that frost-ring formation was so frequent in a spruce 2 meters high that he counted 10 frost rings in a section about 15 years old, so that 25 rings were to be counted in a casual macroscopic examination. The frost-ring formation extended down into the stem parts, which were 10 to 12 years old. In the larch the frost rings occurred only in its youth, as in the spruce, and were found only in the youngest to the 4-year-old axes; in the Lawson cypress, however, frost rings still occurred in the older axial parts, and such ring formation was noted also in the interior of the phloem. Hartig gives the same account later in his textbook of plant diseases (3).

¹ Serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

Petersen (9) describes and illustrates the zone of parenchyma tissue or frost ring which resulted in a double-ring formation in beech trees which had suffered from frost on May 17 and 18 in Holland.

Tubeuf (14, pl. 31, fig. 1), in an article upon the pathological anatomy of spruce trees that were dying back from the top in consequence of drought injury, evidently for the sake of comparison, illustrates a portion of a frost ring in a small tree of *Picea excelsa*. However, he makes no allusion in the text to frost injury, which would seem to be due to his apparent failure to publish the concluding part of the article.

Sorauer, who was able to add the action of frost to the causes which bring about the formation of false annual rings (12, p. 320), later gives the details of an extensive study to determine the effects of early and late frosts on the mature and immature wood of a large number of fruit and forest trees (13). He found that eruptions in the vascular cylinder are generally manifested either in radial clefts within the medullary rays or in tangential cracks within the cambial region. In addition, many cavities appear in the pith and the bark parenchyma. The separated tissue within the cambium region gradually heals over, after presenting the appearance of a ring growth of two years. Sorauer discusses the formation of double rings from the activity of frost and gives the same account of this in the last edition of his manual of plant diseases (12) as well as a detailed account of the injurious action of frost injury in general upon plant tissue. Here (p. 577) he describes the brown circular zones, or "frost lines," frequently occurring in fruit trees after spring frosts and composed of collapsed, misshapen cells. The occurrence of this phenomenon was also investigated experimentally in artificial freezing experiments.

Graebner (1), who investigated the action of late frosts on oak, beech, spruce, and fir, makes no mention of frost-ring formation as such, but does mention a wound-parenchyma formation that can be followed back into the 2-year-old and 3-year-old wood.

Neger (7) investigated a tip blight of *Picea excelsa* with which two ascomycetous fungi were associated; however, they were found only on shoots that had been injured by frost. Sections of the stems, taken both through the dead tips and through the still living stems, showed a more or less broad zone of parenchyma wood or frost ring occurring in the beginning of the 1913 growth ring. Since this parenchyma zone followed immediately upon the summer wood of the 1912 growth ring and was not preceded by normal spring-wood tracheids, it was assumed that a late frost was not involved, but rather an early frost occurring in the fall of 1912. While the frost of 1912 did not come particularly early, relatively low temperatures occurred in comparison with other years, following upon a cold wet summer, which greatly retarded the maturation of the axial growth of that year. This injury therefore was considered to be more nearly due to the action of the winter frost upon immature wood. Tubeuf (15) had previously briefly described and illustrated a tip blight of *Picea excelsa* due to the same causes, but he does not go into the pathological anatomy of the injured shoots. According to Neger, the frost injury had the effect of suspending or at least

reducing the bark pressure, with the result that a zone of parenchyma wood was developed as the first growth in the following spring instead of the normal tracheidal wood, in so far as the stem had remained living and continued its annual ring formation. In his textbook, which appeared later, Neger (8) briefly describes frost rings and reproduces an illustration of one caused by this winter frost.

Somerville (11) describes an abnormal zone of parenchyma tissue that is very closely related to frost rings, if not actually identical with them. This abnormal zone occurred in the early-spring wood of a large percentage of young conifers whose wood he had occasion to examine. All of the species examined, including *Larix leptolepis*, *Pseudotsuga douglasii* (= *P. taxifolia*), *Tsuga albertiana* (= *T. mertensiana*), *Cedrus deodara*, *Thuja plicata*, and *Picea sitchensis*, exhibited more or less of the injury.

Somerville describes the abnormal wood formation only for *Larix leptolepis*. He says that the abnormal wood formed in the early part of 1912 is easily distinguished by the naked eye. On a cross section it appears as a narrow brown ring, while on a radial section it forms a thin brown streak. A microscopic examination shows that the medullary rays are seen to pursue a most irregular course and to consist of much elongated and swollen cells. The rays frequently are discontinuous with those of the previous ring. The intervening cells, many of which have walls much thickened, instead of getting smaller as one proceeds outward, have a tendency to become larger. A radial section along the junction of the normal summer wood and the abnormal spring wood of 1912 shows that the abnormal zone of tissue is largely composed of irregularly shaped parenchymatous cells with simple pits and rectangular transverse walls. It will thus be seen that the foregoing description of Somerville's abnormal wood formation agrees closely with Neger's description of frost rings, especially since they occur following immediately upon the summer wood of the preceding growth ring.

Somerville, however, states that the cause would appear to be the excessive heat and drought of the summer and fall of 1911, which seriously affected the growth of many trees, notably the Japanese larch. He says:

This climatic condition evidently so upset the normal function of the cambium that when the wood of 1912 came to be formed it was found to deviate greatly from the usual type.

However, from a consideration of Somerville's description and illustrations of the injury, together with the fact that it occurred also in the spring wood of other years, the writer is inclined to regard this injury as the result of frost rather than of drought. This view appears to gain credence when it is considered that, inasmuch as the drought occurred during the summer of 1911, it would seem likely that the injury to the cambium must have occurred in ample time to have registered in the latter part of the 1911 ring, whereas it did not register until the beginning of the growth ring of the following year.

Mix (6) describes and illustrates the formation of a zone of parenchyma wood in apple trees varying in age from 2 to 8 years, following an injury to the cambium due to freezing while in the dormant

condition. Macroscopically the injury appeared as a brown line between two annual rings. A microscopic examination showed that the wood first formed in the spring following the injury was a comparatively narrow zone of parenchyma wood, that the normal xylem was soon laid down outside of this zone, and that the remainder of the growth ring was normal. The medullary rays, which had become enlarged and spread out tangentially, could be traced into this parenchyma zone. Mention is made of a yellowish brown amorphous substance occurring in the intercellular spaces. While Mix was unable to definitely determine the exact nature of this substance, the writer, from his investigation of this group of substances (10), would regard the brown color as a sign of humification and the brown substance itself as a huminlike compound originating as a decomposition product of the cell contents of the cells killed by frost. The type of frost injury which Mix described is closely related to that described by Neger (?) in *Picea excelsa*.

GENERAL SYMPTOMS AND MACROSCOPIC APPEARANCE.

During the field season of 1921 the writer repeatedly observed in frost localities on cut-over lands in Washington, Idaho, and Montana areas of coniferous reproduction on which a large percentage of the young trees showed the effect of repeated late frosts, both externally and internally.

In unusually severe cases the young growth had been killed back until the trees had developed an abnormally compact bushy form.² Such a growth form, which was by no means common in such native trees as *Thuja plicata*, *Tsuga heterophylla*, *Pseudotsuga taxifolia*, *Larix occidentalis*, *Picea engelmanni*, *Abies lasiocarpa*, and *Tsuga mertensiana*, was rarely observed in *Pinus contorta*, *P. ponderosa*, and *P. albicaulis*.³ It was extremely common, however, in *Abies grandis* (Pl. I, A). The greater tendency of young trees of *Abies grandis* to assume this compact bushy form after injury by late frost is due to the great readiness with which this species develops compensatory shoots. Since the recovery of any given species from frost injury depends largely upon its ability to retain dormant buds which give rise to such compensatory shoots, it should rank very high in both *Abies grandis* and *A. concolor*.

In the cases of less severe injury the trees did not develop any particularly compact bushy form and often did not appear unusual in any way, yet the same frost rings occurred in the wood, although less frequently and perhaps only in the wood increment of but a single year. Where such frost rings occurred, however, it could be detected upon close examination in practically all cases investigated by the writer that the original terminal shoot of the stem in question had been killed back by frost after the initiation of its growth, and that in some cases the same had happened one or more times to the volunteer shoots. In this connection the writer wishes to state that he has never observed in any of the coniferous species studied

² The writer wishes to make it clear that he does not consider all cases of the brooming of young conifers to be due to late-frost injury, since this abnormal form of growth may be induced by parasitic fungi alone. In the latter case, however, the formation of frost rings does not occur within the zones of annual increment.

³ Host names for American species follow the usage in the publications of George B. Sudworth, of the United States Forest Service.

by him any pronounced permanent distortion of the living shoots which would indicate injury by late frost, except in the case of *Pinus densiflora* Sieb. and Zucc., a Japanese species which will be considered later.

In every case where the terminal growth had been killed, a narrow brownish zone of abnormal tissue, or frost ring, could be traced from the base of the dead shoot down the stem for a distance of several inches, or often for several feet in the case of saplings. This zone of abnormal tissue, which has the appearance of a brownish stripe in sections of the stem, usually occurred in the immediate beginning of the growth ring or else a short distance beyond the outer limit of the growth ring of the preceding year. In the latter case it gave the appearance of a double ring formation, especially when the growth rings were rather narrow. As a rule, the action of late frost manifests itself in a closed ring, although occasionally the zone of injury appears only on one side of the stem. In no case of late-frost injury observed by the writer was any external sign of mechanical injury to the bark visible.

Measurements of the linear extent of the frost rings were made in only a few instances where larger trees were involved, since this point was not deemed of any particular importance. In general, it may be said that in the smaller trees they usually extend down to or nearly to the ground line. In the larger trees, however, they terminate rather abruptly as the older and therefore better protected portion of the stem is reached. While the writer has observed the occurrence of frost rings in the outer growth rings of saplings of *Larix occidentalis* and *Pseudotsuga taxifolia* 2 inches in diameter, he has not observed their occurrence in coniferous stems of larger size at the time of the injury. Frost-ring formation, however, often occurs in larger stems of fruit trees that are subject to various forms of frost injury. The latter in general, however, perhaps due in part to the cultural practices employed, are more susceptible to frost injury than the coniferous trees. Detailed stem-analysis data are recorded for four saplings of *Larix occidentalis* from an area in which frost rings were found to be especially numerous, as mentioned below.

STEM ANALYSIS OF *LARIX OCCIDENTALIS* SAPLINGS WITH FROST RINGS, CUT AT IONE, WASH., AUGUST 24, 1920.

Tree No. 1.—The tip of the original leader formed in 1918 had been killed and was dead down to an elevation of 223 centimeters above the ground, at which point a 2-year-old volunteer had developed subsequent to the injury, giving the sapling a total height of 278 centimeters. A conspicuous brownish zone of parenchyma wood, located in the 1919 growth ring and developed very soon after the initiation of the growth of that year (Pl. II, C), could be traced down the stem to an elevation of 65 centimeters above the ground, at which point it was no longer apparent under a hand lens. A section of the wood at this point showed under the microscope practically no distortion of the wood elements.

Tree No. 2.—Another sapling, with a height of 365 centimeters and with no evidence of any external injury or dead terminal shoot, showed upon dissection a similar brownish zone of parenchyma formed shortly after the beginning of the 1919 growth ring. This line of parenchyma could be traced from the apex of the 1918 growth, at an elevation of 300 centimeters, down the stem to an elevation of 175 centimeters, below which point it was no longer in evidence.

Tree No. 3.—In this case the original leader had been killed, and a volunteer leader 2 years old had been put out at a height of 158 centimeters, just below the dead tip of the 1918 growth. A brownish zone of parenchyma, formed shortly after the beginning of the 1919 growth ring, was traceable down the stem

directly from the base of the volunteer leader, at an elevation of 158 centimeters to an elevation of 30 centimeters above the ground. In these first three trees there was no evidence of any frost injury in the growth rings of any year other than those enumerated.

Tree No. 4.—The original leader of this sapling had been killed, and a 2-year-old volunteer had been established at a height of 237 centimeters just below the dead tip of the 1918 growth, giving the tree a height of 300 centimeters. A conspicuous brownish zone of parenchyma, developed shortly after the beginning of the 1919 growth ring, could be traced from the apex of the growth of this year, at the base of the dead 1918 tip, at an elevation of 237 centimeters, down the stem to an elevation of 75 centimeters. At this point a faint zone of parenchyma also showed in the beginning of the 1918 growth ring and could be traced up the stem to an elevation of 200 centimeters, a point just below the apex of the 1918 growth, where the stem had a diameter of but 2 millimeters. Beyond this point the injury was not evident with a hand lens, but only in sections examined under the microscope. By means of a microscopic examination this zone of parenchyma formation could be traced up to an elevation of 211 centimeters, at which point the stem, consisting of only the 1918 growth, was but 1 millimeter in diameter, or practically to the apex of the growth ring of that year.

Through the kindness of J. A. Larsen, director of the Priest River Experiment Station in Idaho, the writer was enabled to examine and procure material for the study of a number of non-indigenous conifers that showed the effects of repeated late-frost injury. The trees had been grown to the transplant stage in California and planted some years previously on an open bench at the experiment station. The stock in question comprised young trees of *Pinus lambertiana*, *Pseudotsuga taxifolia*, *Chamaecyparis lawsoniana*, and *Sequoia washingtoniana*, all of which except *Pseudotsuga taxifolia* are nonindigenous to Idaho. All of these trees, especially the two species mentioned last, exhibited an abnormally compact and bushy form and owing to the repeated injury contained frost rings in practically every growth ring. At the time of the examination all of the two species last mentioned, as well as a large number of the first two species, were dead, due probably to the combined action of the repeated late-frost injury and recent drought injury.

The young shoots, however, are by no means always killed back by late frost. Not infrequently the shoots injured by frost may remain alive throughout and still record the injury within their tissues in the usual manner. In this form of late-frost injury the terminal shoots as well as the corresponding lateral shoots sometimes exhibit more or less of a characteristic permanent distortion, which is accompanied by a frost-ring formation in the wood. While not observed in any of the western frost-injured conifers which the writer studied, this type of injury has been described by Hartig (2) for *Pinus sylvestris* and has been observed by the writer in a row of young trees of *Pinus densiflora*, a Japanese species of dwarf bushy pine grown in a nursery on the Mall, in Washington, D. C. For the correlation of this form of injury with late frost and the observations on the behavior of the trees immediately after the freezing the writer is indebted to R. H. Colley and G. F. Gravatt, of the Office of Investigations in Forest Pathology.

From March 27 to 29, 1921, there occurred a general cold wave, coming after a period of abnormally warm weather, which was very destructive to the active vegetation over a large part of the country east of the Mississippi River. On the day following this freeze, March 30, it was observed that large numbers of the 1921 shoots

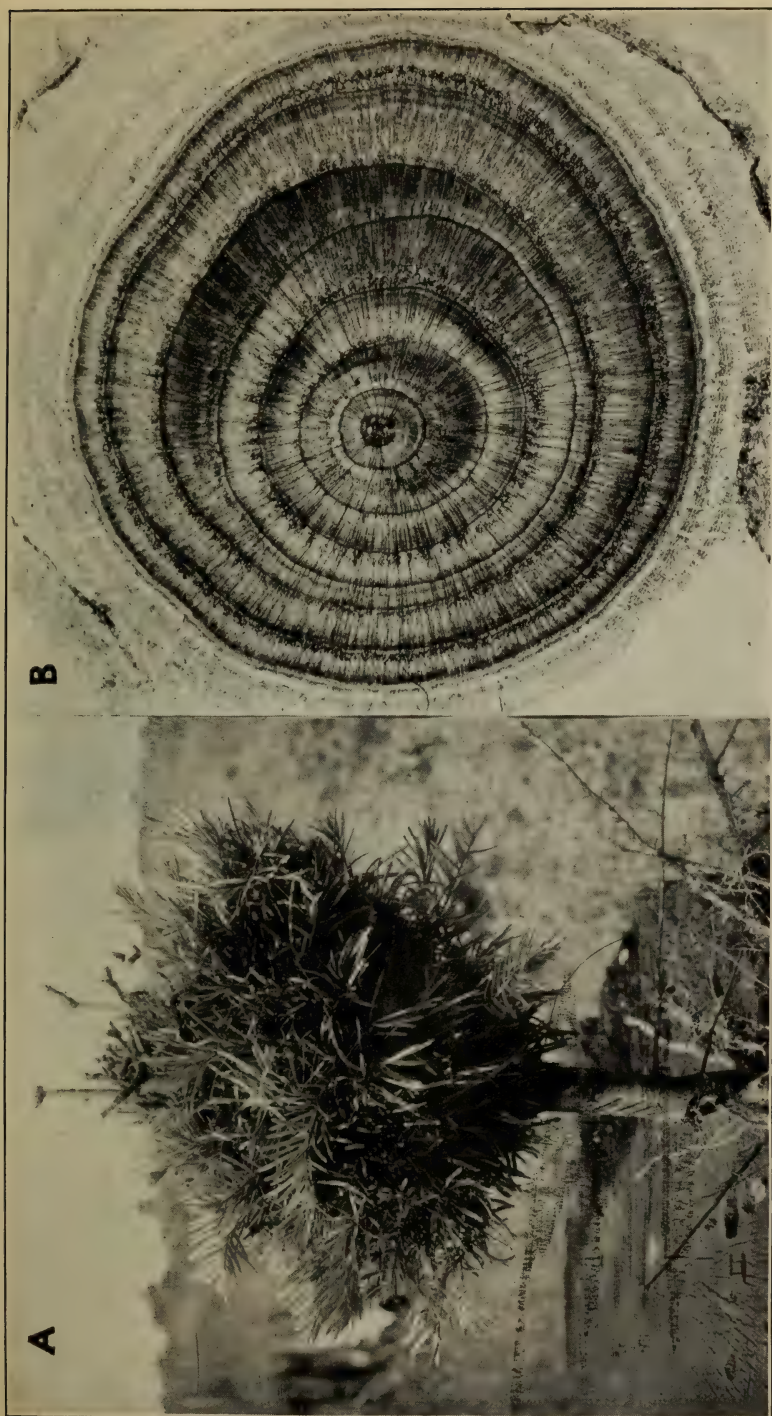
along this entire row of *Pinus densiflora* trees, which was the outermost row on one side of the nursery, had wilted and drooped, due to loss of turgor. On a row of trees of *Taxus baccata* near by in the same nursery it was observed that a large number of the new shoots, which averaged half an inch in length, were killed outright.

On September 30 the writer had the opportunity to observe these trees. The entire row of *Pinus densiflora* trees showed numerous cases of permanent deformation of the terminal and many of the lateral shoots of the last whorl, but all had remained living and had regained to a large extent their normal erect position, although not without leaving more or less of an S-shaped kink in their stems (Pl. III). In all cases which the writer examined, such shoots exhibited a frost ring in the beginning of the 1921 growth ring, which could be traced readily down the stem for several inches from the base of the last whorl, although it was scarcely to be distinguished, even with a hand lens, from the outer limit of the 1920 growth ring, owing to its close coincidence (Pl. IV, A). The frost ring likewise was traceable macroscopically on sections cut with a keen microtome knife, though better microscopically, for a distance of several centimeters above the bases of the deformed terminal and lateral shoots of the last whorl, where it appeared in the first wood elements bordering upon the pith and in the outer cells of the pith. It was lacking in those few lateral branches of the last whorl that sometimes escaped injury by reason of their lack of development at the time of the freeze. In the far less numerous cases of frost injury in *Taxus baccata*, however, there was no evidence of any deformation of the young shoots, such as occurred in *Pinus densiflora*, but the young terminal shoots were killed outright and replaced by one or more volunteer shoots. In all such cases, where the terminal shoot had been killed by late frost, a frost ring could be traced down the stem for several inches below the base of the dead terminal shoot in the beginning of the 1921 growth ring.

A row of trees of *Pinus montana* var. *uncinata*, a more hardy appearing species planted next to the row of *Pinus densiflora*, showed no single external symptoms of frost injury, and none of the shoots which the writer cut into showed any frost rings. On the other hand, with the exception of the two species mentioned, there was no evidence of any deformation or killing of the shoots by frost on any of the other conifers, of which a large variety were in the nursery.

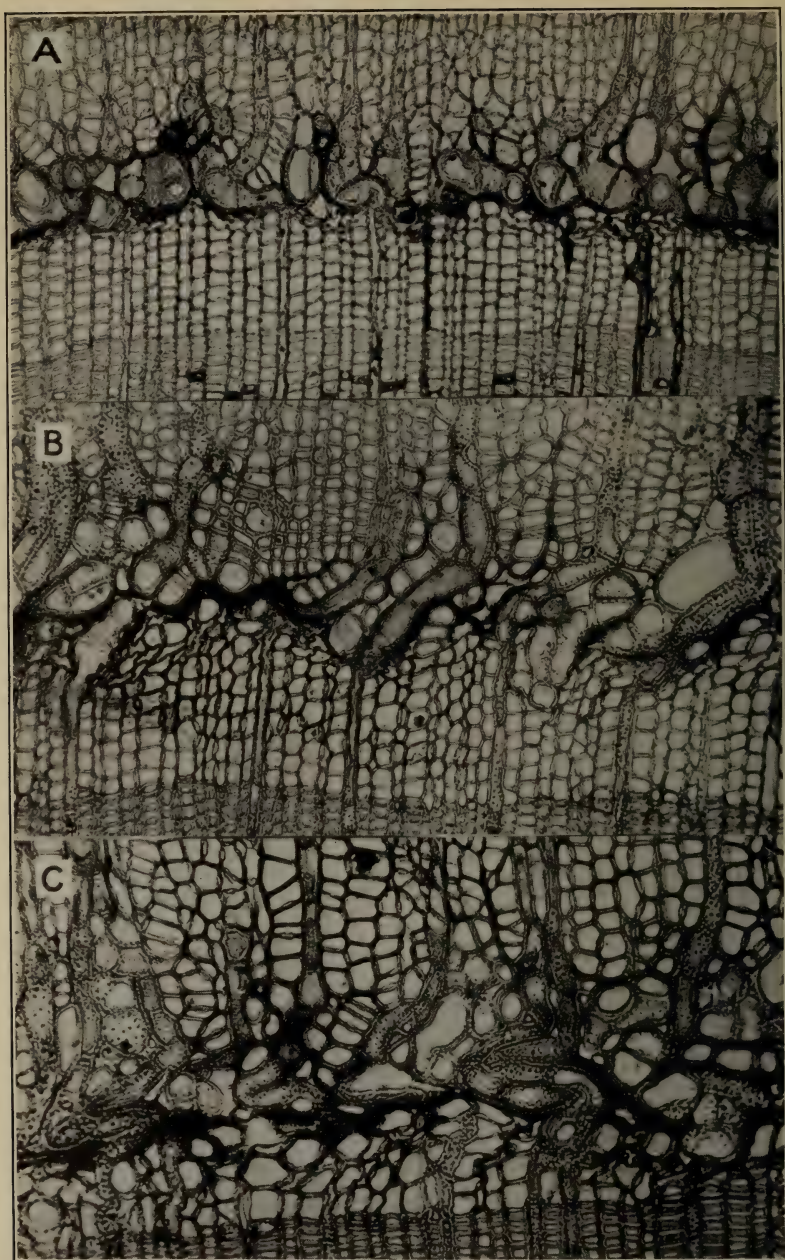
ANATOMICAL STRUCTURE OF THE FROST RINGS.

As is well known, when living plant tissue is frozen the water is withdrawn from the cells, solidifying to ice in the intercellular spaces or other tissue gaps. Upon the initiation of the freezing the water from the still living cambial wood passes out between the wood and the bark and forms an ice mantle there. The extraordinarily tender nature of the youngest cambial cells favors the separation of the tissue, and a loosening of the phloem is facilitated either by the stronger shrinkage of the frozen wood or by the expansion of the cortex due to the stress exerted by the ice formation beneath it. The lower the temperature falls the thicker the ice mantle becomes, and it compresses the tender cambial cells until their outlines are more or less indistinguishable, as is to be seen in Plate IV, A, B, and C.



FROST INJURY TO *ABIES GRANDIS* AND *TSUGA HETEROPHYLLA*.

A.—Young tree of *Abies grandis* repeatedly injured by late frosts, showing the abnormally compact and bushy form of growth as a result of the ready development of numerous compensatory shoots. This tree exhibited frost rings in practically every growth ring. (One-fifth natural size.) B.—Transverse section of a branch of a similar tree of *Tsuga heterophylla*, showing frost-ring formation, either partially or entirely around the stem, in every growth ring after the first one. ($\times 10$.)



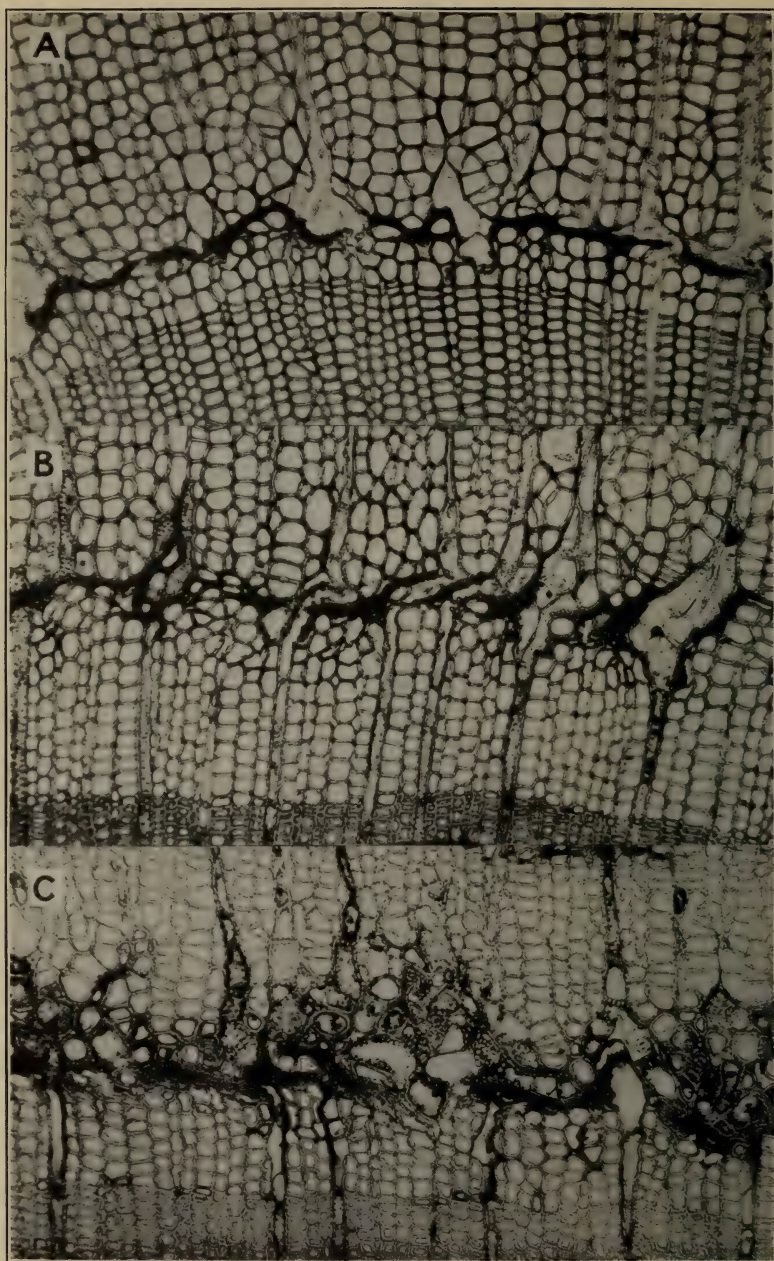
FROST INJURY TO *THUJA PLICATA*, *PSEUDOTSUGA TAXIFOLIA*, AND *LARIX OCCIDENTALIS*.

- A.—Transverse section through frost ring in *Thuja plicata*, showing a pronounced distortion of the medullary rays. ($\times 135$.) B.—Transverse section through frost ring in *Pseudotsuga taxifolia*, showing the crumpling of the wood cells that were but slightly lignified at the time of freezing. ($\times 135$.) C.—Transverse section through frost ring in *Larix occidentalis* sapling (tree No. 1), at 146 centimeters above the ground, showing an extreme case of lateral displacement of the medullary rays. ($\times 135$.)



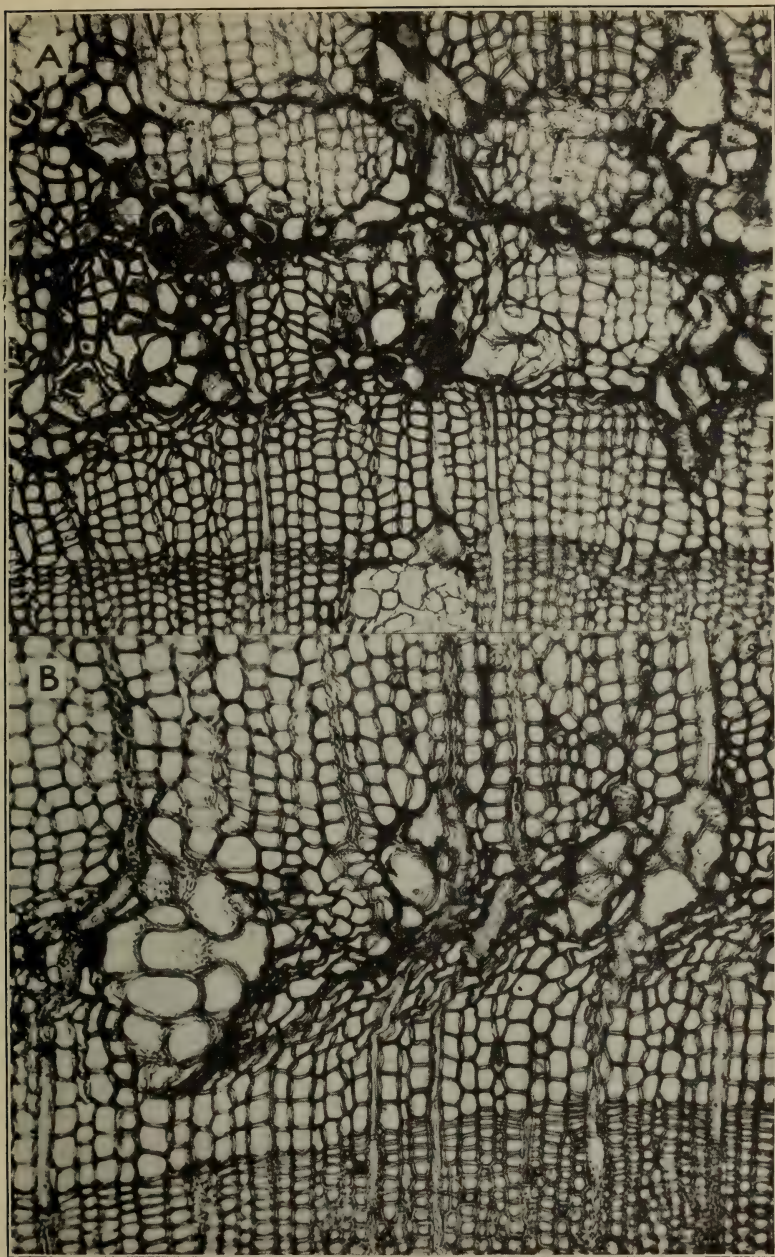
FROST INJURY TO PINUS DENSIFLORA.

Effect upon *Pinus densiflora* of a late March frost occurring after the development of many of the 1921 shoots had been initiated, showing the characteristic permanent distortion of the terminal shoot and three of the five lateral shoots. Photographed September 30. (Two-thirds natural size.)



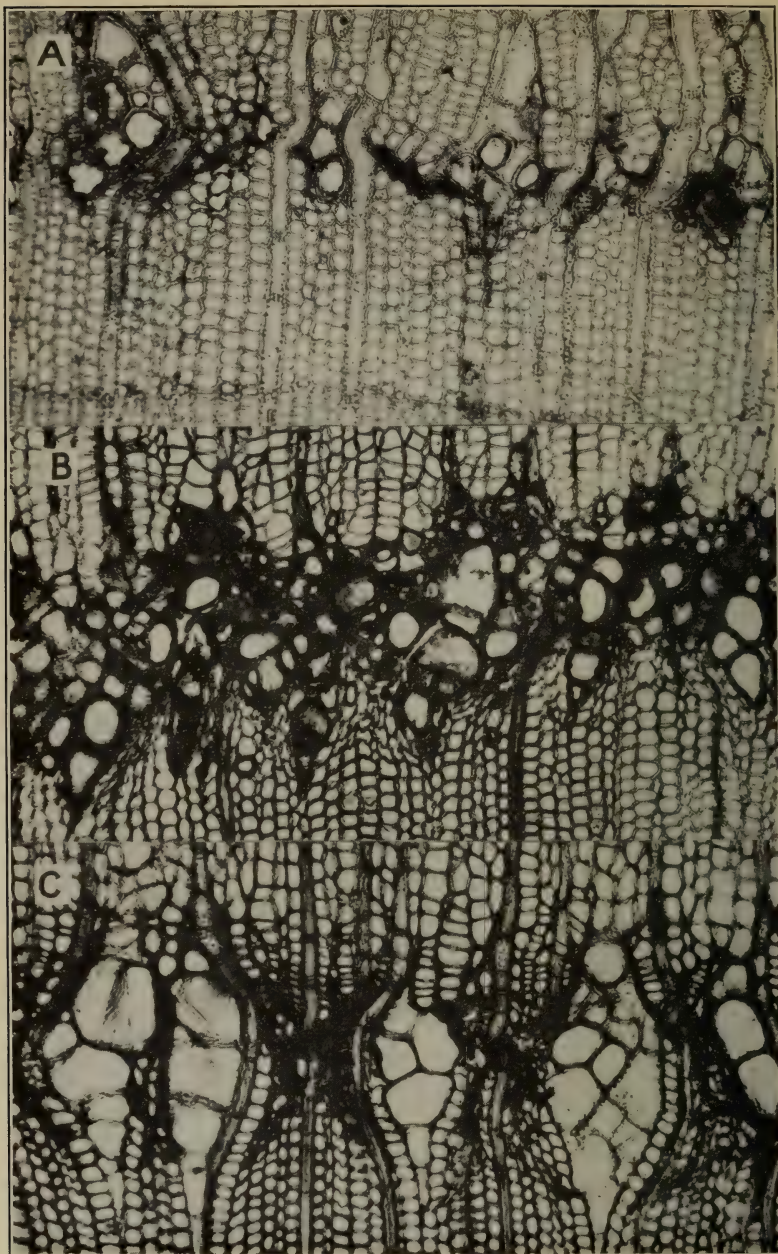
FROST RINGS OF *PINUS DENSIFLORA*, *ABIES GRANDIS*, AND *TSUGA HETEROPHYLLA*.

A.—Transverse section of stem of *Pinus densiflora* taken 10 centimeters below the 1921 whorl of branches, showing a slight frost ring formation in the 1921 growth. ($\times 135$.) *B.*—Transverse section of *Abies grandis*, showing a more pronounced frost-ring formation, with the characteristic lateral displacement of the medullary rays and their proliferation. ($\times 135$.) *C.*—Transverse section through a frost-ring formation in *Tsuga heterophylla*, showing the formation of a broad zone of parenchyma wood ($\times 135$.)



FROST INJURY TO *PINUS MONTICOLA* AND *PINUS ALBICAULIS*.

A.—Transverse section through a stem of *Pinus monticola*, showing the termination of the preceding annual ring (at the outer margin of the resin canal at bottom of picture) and three frost rings occurring in the early portion of the succeeding growth ring. ($\times 135$.) B.—Transverse section through a frost ring in *Pinus albicaulis*, showing the crumpling of the wood cells that were but slightly lignified at the time of freezing and the formation of a radial cleft (at the left) which has become filled by large-celled parenchyma. ($\times 135$.)



FROST INJURY TO *TSUGA MERTENSIANA*, *CHAMAECYPARIS LAWSONIANA*, AND
SEQUOIA WASHINGTONIANA.

- A.—Transverse section through frost ring in *Tsuga mertensiana*, showing the outer face of a preceding growth ring at bottom and a large number of well-lignified tracheids developed before the freezing; also a radial cleft (at upper left-hand corner) filled up with large-celled parenchyma. ($\times 135$.) B.—Transverse section through a frost ring occupying a median position in a growth ring of *Chamaecyparis lawsoniana*, showing an unusually broad zone of dark-brown parenchyma and radial clefts also filled up with large-celled parenchyma. ($\times 135$.) C.—Frost ring occurring at the outer limit of a summer-wood formation in *Sequoia washingtoniana*, showing a series of radial clefts subsequently filled up with large-celled parenchyma. ($\times 135$.)

The already thick-walled but still unligified cells collapse also, their walls presenting a crumpled appearance (Pl. II, *B*; Pl. V, *B*).

After the thawing, the cell tissue that has been compressed does not expand to its previous form and size, but remains permanently distorted. In the cases of the more severe injury there begins at the periphery of the wood formed before the injury a more or less broad zone of large-celled parenchyma, which is distinguished by its greatly thickened simple-pitted walls and by the dark-brown color of the walls and the cell contents. This zone of parenchyma tissue quickly passes over into tracheidal tissue, which at first is usually somewhat larger celled than that developed before the frost injury, but which quickly becomes typical. In this manner the frost injury results in the formation of a false ring, especially if it occurs after the development of several spring-wood tracheids (Pl. IV, *B*; Pl. V, *A*; Pl. VI, *A* and *B*).

As may be seen from the accompanying reproductions of photomicrographs, the frost rings exhibit great dissimilarity in structure, according to the degree of intensity of the frost action and the susceptibility of the wood tissue at the time of its occurrence.

The medullary rays, which extend through the frost ring and stretch in accordance with the stress exerted upon them, naturally suffer most from the displacement of the tissue. Their deformation varies according to the severity of the injury, but in general is very characteristic. On the inner side of the frost ring the rays widen out abruptly, often becoming 2-seriate or 3-seriate instead of uniseriate (Pl. IV, *B*; Pl. II, *B*). The rays apparently are stimulated to lateral broadening by the diminution of the pressure normally exerted by the adjoining wood elements, caused by the crushing together of the young wood elements. This broadening ensues immediately in the region of the frozen young wood and reaches its greatest extent within the region which, in the frozen condition, was filled by ice. In addition to broadening out laterally, the rays usually are also more or less sharply displaced, often undergoing a knee-shaped bending (Pl. II, *A* and *C*). Within any one stem the medullary rays are usually, although by no means always, displaced uniformly either to the one side or to the other. As the wood ring enlarges after the thawing, the medullary rays are brought into an oblique position and later grow out again in their original direction, continuing in equal number in the newly formed wood and causing the wood tissue to appear as though a fault had occurred in it. The lateral displacement of the medullary rays apparently depends upon the circumstance that their stretching during the ice formation remains preserved after the thawing. This lateral expansion and displacement of the medullary rays is by far the most conspicuous and characteristic feature of late-frost injury and is a constant feature of all injuries to wood by late frost. In at least the more severe cases of injury the frost ring is further accentuated by a more or less broad zone of brownish parenchyma tissue.

There also may arise after the thawing a series of radial gaps or clefts, occurring with variable frequency and conspicuousness within the tracheidal tissue, where it had been stretched apart previously by the excessive tangential contraction. With subsequent growth, these tissue gaps become filled with large-celled parenchyma

derived from the new cambial formation (Pl. V, *B*; Pl. VI, *B* and *C*.) An unusually striking example of this radial cleft formation occurred in the frost rings observed in stems of *Sequoia washingtoniana*, where clefts were present not only in the early formed portion of the growth ring but also at the outer limit of the summer-wood formation (Pl. VI, *C*). In the latter case the frost rings appeared to lie between the summer wood of one growth ring and the spring wood of the next, so that there was no sharp demarcation between the two annual rings except where the frost ring did not extend completely around the stem. Still other stems from the same material, which had been injured by frost near the close of the growing season and had died without subsequent growth, exhibited the same radial clefts at the periphery of the xylem, but in this case the clefts were still open and free from any occlusion by parenchyma cells. Such tissue disturbances result in a very pronounced false ring formation.

A large part of the phenomena which come to light in frost injuries to young stems, however they may vary, can be traced to simple mechanical processes. Sorauer (12) has proved experimentally that processes of loosening are initiated in the cell membranes by the action of frost; and this explains the formation of this parenchyma zone instead of the normal wood elements as the result of a weakening of the compressing influence exerted by the bark girdle on the youngest tissue, that is, the cambium. According to Sorauer, the frost, without necessarily forming ice crystals in the intercellular spaces, contracts the tissue in direct proportion to the thinness of the walls of the tissue. The bark suffers considerably more than the wood, which, reached later, cools down less easily and contracts less. The tangential contraction is greater than the radial. As Sorauer states, this difference acts like a one-sided strain and exerts itself in the direction of the circumference of the trunk, to which the different layers of the bark will respond to a different degree when the bark as a whole is very young. Consequently, with the action of the frost there must take place everywhere within a woody axis a preponderance of tangential strain over radial contraction, and under certain circumstances this must increase to a radial splitting of the tissue. With an equal degree of contraction at all points in the bark, the cells lying nearest the periphery and most elongated in the direction of the circumference of the trunk will be the most displaced. As Sorauer also states, if one considers that the outer cells of the primary bark, because of the greater coarseness of their walls, are not as elastic as the underlying thinner walled ones, it is clear that when the strain ceases in them the permanent stretching, caused by the incomplete elasticity, will be the greatest there. After the action of the frost, which continues but a short time in late frosts, has stopped, the tissue that has become stretched is not sufficiently elastic to contract again to its original volume, and the cells retain their distended and distorted form. In this way each frost action leaves behind an excessive lengthening of the peripheral tissue layers in proportion to the adjacent layers which lie more toward the inside. The bark body as a whole is therefore larger and either does not have room enough on the wood cylinder, so that in places it is raised up from it, or it at least decreases its constricting influence on the

cambial elements of the wood cylinder. The cambial zone responds to this with the formation of parenchyma wood, as may be seen in every wound in which the bark is raised. If the bark girdle closes together again into a connected layer the cambial cylinder by growth in thickness must again resist the constricting effect of the bark and on this account again forms normal wood elements.

In sections containing frost rings that when viewed macroscopically appear to be only one-sided, it can be recognized in a microscopic examination that, as a rule, a lesser disturbance has occurred on the other side of the stem (Pl. II, *B*). However, a disturbance of the wood tissue by no means always extends entirely around the stem, the same often being purely local and consisting of numerous isolated groups of parenchyma elements. The frost rings occasioned by late frost vary greatly in their position within the growth ring, but usually occur early in the spring wood, either in the immediate beginning or after the formation of a few normal tracheids. On the other hand, they may not be formed until late in the growth ring when the frost must necessarily occur during the summer. Frost rings in the latter position are comparatively rare, however.

More than one frost ring may occur within the wood of any one growth ring, depending upon whether or not the frost occurs more than once after the spring growth has been initiated. Two frost rings within one annual ring are fairly common, and the writer has observed the occurrence of three frost rings in the spring-wood zone of an annual ring in *Pinus monticola* (Pl. V, *A*) and in *Picea engelmanni*.

Frost-ring formation may occur in the wood from the action of either late or early frosts during the course of the growing season or from the freezing of the cambium during the winter when the tree is dormant. The frost rings, therefore, may register at any point within the growth ring, the relative position of the frost ring within the growth ring signifying the time at which the injury occurred.

According to Hartig (2, p. 4), frost rings arise through late-frost injury only when the cambial activity has already commenced and at least some few cells have been cut off toward the interior, if, therefore, the annual ring formation has been initiated. It has been the writer's experience with late-frost injury that, while the number of spring-wood tracheids that intervene between the outer limit of the summer wood of the preceding annual ring and the frost ring is usually fairly uniform on any radius, the frost rings sometimes appear to abut directly on the summer wood of the preceding growth ring, although groups of normal spring-wood tracheids usually intervene in places. The formation of at least some normal spring-wood elements would therefore appear to be a diagnostic feature of late-frost injury.

In the case of late frost occurring unusually late in the season, the frost rings may register in the median or outer portion of the growth ring (Pl. VI, *B*). In the case of early frosts occurring late in the season, at a time when the annual accretion of wood has not matured, or in the case of frost injury occurring during the dormant period of the year, the resulting frost ring registers in the immediate beginning of the next growth ring, often tending to obscure the normally sharp demarcation between the two rings (Pl. VI, *C*).

In general, it appears that frost injury occurring shortly after the initiation of active growth causes a greater distortion of the wood elements than that occurring when the growth ring is practically mature or when the tree is dormant.

Frost rings are often confusing to those who have occasion to engage in age determinations or stem analyses of trees. The frost-ring formation, however, usually occurs within such close limits of the beginning of the annual ring formation that, macroscopically at least, the parenchyma zone appears to coincide more or less closely with the outer limit of the preceding growth ring. Frost-ring formation should prove confusing in age counts only when it occurs late in the season after a considerable portion of the growth ring has been formed. Moreover, since only the younger stems appear to be susceptible to frost-ring formation, it is believed that in conifers at least, false ring formation from this source need be expected chiefly only in the first several growth rings formed in the life of the tree.

As may be expected from their structure, frost rings constitute a plane of weakness in the wood, since there is no strong bond between the wood formed before the injury and the parenchyma wood formed immediately after it. In chopping off a face on stems containing one or more frost rings in order to follow their linear extent, the wood frequently splits peripherally along the plane of these zones of abnormal wood. In future years it seems likely, as Somerville (11) states for the abnormality which he describes, that they may lead to the formation of ring shakes within the trees.

The writer's investigation of the pathological anatomy of late-frost injury confirms those of Mayr, Hartig, and Sorauer in all particulars except the occurrence of the chains of pathologic resin canals, which Mayr (4) suggests may be caused by frost and which Hartig (2) found sometimes associated with the frost rings.

Mayr (4, p. 29), in a discussion of the chains of abnormal or pathologic resin canals sometimes found in the wood of *Abies firma* and *Tsuga*, suggests that they may be caused by late frost, which, he states, is of fairly common occurrence. However, he observed that such chains of resin canals may also be found in the hard summer-wood zone of the annual ring, where late frost is excluded as a cause. Although not considered by Mayr, a number of other types of injury could easily have been responsible for this pathologic resin-canal formation.

Hartig (2, p. 7) states that he has repeatedly found that the wound parenchyma developing in the frost ring contained resin canals, so that a more or less complete ring of them was recognizable in the frost zone. Despite the writer's particular consideration of this point and his extensive investigations on pathologic resin-canal formation in general, which will appear shortly, he has never observed the formation of chains of pathologic resin canals as the result of frost injury. While zones of pathologic resin canals do occasionally coincide with the frost rings in a stem, the writer has always traced their origin to some mechanical wound. It is by no means impossible, however, for such zones of pathologic resin canals to arise schizogenously within the broad aggregates of parenchyma wood comprising the frost ring.

Hartig (2, p. 7) likewise mentions the occurrence of chains of abnormal resin canals, which he regards as due to the action of late frost, throughout the entire circumference of the phloem of stems of *Chamaecyparis lawsoniana* 2 centimeters thick, at a slight distance from the cambial layer. He states that these arise by the medullary rays stretching and becoming broadened laterally through cell division and that between each two rays the delicate-walled tissue composed of sieve tubes and parenchyma was crowded apart. He assumes that here also the tissue gaps are not closed after the thawing of the ice, and finds that the surrounding living cells become enlarged more or less into these gaps and become converted into resin-secreting cells, pouring large quantities of resin into them. As a result of this formation a festoon of large resin beads appears from the bark on the ends of cut-off shoots. The writer, however, did not observe any formation of chains of pathologic resin canals in the phloem of the frost-injured material of *Chamaecyparis lawsoniana* studied by him.

SUMMARY.

The pathological anatomy of late-frost injury has been studied in detail by the writer in *Pinus albicaulis*, *P. contorta*, *P. densiflora*, *P. lambertiana*, *P. monticola*, *P. ponderosa*, *Picea engelmanni*, *Larix occidentalis*, *Pseudotsuga taxifolia*, *Abies grandis*, *A. lasiocarpa*, *Tsuga heterophylla*, *T. mertensiana*, *Thuja plicata*, *Chamaecyparis lawsoniana*, *Sequoia washingtoniana*, and *Taxus baccata*; also in apple and pear trees.

The young shoots injured by late frost may either wilt through loss of turgor and after again directing their points upward usually become permanently distorted, or, as generally happens, they may be killed outright and replaced by one or more volunteer shoots. The structural disturbance initiated by the action of late-frost injury is not confined to the shoots then developing, but extends down the stem for distances varying from several inches to several feet below the base of the injured shoots, or as far as the cambium has been injured by the freezing without entailing the death of the stem. The healing proceeds internally and results in the formation of a brownish zone of parenchyma wood, or frost ring, within the growth ring, developing at the time of the injury.

Late-frost injury results in very characteristic disturbances in the tissue of the growth ring forming at the time of the injury. The abnormal tissue of the frost ring varies greatly, according to the severity of the injury, and may be characterized by various combinations of such features as the crumpling of the wood cells that were but slightly lignified at the time of the injury, a marked broadening or proliferation of the medullary rays, a strong lateral displacement of the medullary rays together with a marked broadening or proliferation, the presence of radial clefts subsequently filled up by large-celled parenchyma, and more or less broad zones of wound parenchyma. The displacement of the medullary rays is occasioned by their stretching and lack of elasticity; the radial clefts, to the preponderance of the tangential contraction over the radial contraction; and the interpolated zone of parenchyma wood, to a transitory weakening of the compressing influence exerted by the bark girdle on the cambium, due to the disrupting action caused by the freezing.

Frost-ring formation may occur in the wood from the action of either late or early frost during the course of the growing season or from the freezing of the cambium during the winter when the tree is dormant. The frost rings, therefore, may register at any point within the growth ring, the relative position of the frost ring within the growth ring signifying the time at which the injury occurred.

Frost rings arise through late frost only when the cambial activity has already commenced and some new xylem cells have been differentiated. As a rule, there is a definite zone of spring-wood tracheids intervening between the outer limit of the summer wood of the preceding annual ring and the frost ring. In the case of early frosts the frost ring may either register late in the summer wood of the growth ring or not until the immediate beginning of the ensuing growth ring. Frost injury occurring during the dormant period likewise is recorded as a frost ring in the immediate beginning of the ensuing growth ring.

Young trees injured by repeated frosts often develop an abnormally compact and bushy form, especially in *Abies grandis* and other species, which readily form compensatory shoots. Frost injury that results in the killing of the young shoots often detracts greatly from the straight axial growth of the trees and, where frequently repeated, may render the tree absolutely valueless for commercial purposes. In addition, late-frost injury may render young conifers more susceptible to weakly parasitic fungi than they would be otherwise.

Late-frost injury, when occurring late in the season after any considerable portion of the growth ring has been formed, results in a false or double ring formation, which is often confusing in age determinations. Frost-ring formation from late-frost injury has not been observed by the writer in coniferous stems larger than 2 inches in diameter, although it often occurs in larger stems of fruit trees that are subject to various forms of frost injury.

As may be expected from their structure, frost rings constitute a plane of weakness in the wood, which may not only predispose to the formation of circular shake in the standing tree, but may require the manufactured wood to be discriminated against for use in small pieces where great strength is required.

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PROFESSIONAL PAPER

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THE DETERIORATION OF FELLED WESTERN YELLOW PINE ON INSECT-CONTROL PROJECTS.¹

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INTRODUCTION.

During the past 15 years extensive insect-control measures have become necessary in various localities in the western United States in order to check epidemics of the western pine beetle (*Dendroctonus brevicomis* Lec.) and the mountain-pine beetle (*Dendroctonus moniticolae* Hopk.) on western yellow pine (*Pinus ponderosa* Laws.), lodgepole pine (*Pinus contorta* Loud.), western white pine (*Pinus monticola* Dougl.), and sugar pine (*Pinus lambertiana* Dougl.). Briefly, control consists in felling and barking the infested trees (or burning the bark in the case of *Dendroctonus brevicomis*), in order to destroy the overwintering stages of the beetles. The trees usually are limbed well into the top but are not cut into log lengths.

The attacks of the western pine beetle on western yellow pine have been widespread, and consequently the most extensive control projects have been concentrated on this tree species. At present control work is under way in the yellow-pine regions of British Columbia and central California, while a large project was begun in the spring of 1922 in the Klamath Lake region of southern Oregon.

The southern Oregon-northern California project begun in the spring of 1922 necessitated the felling of about 16,000 merchantable western yellow pines, with an occasional sugar pine, comprising ap-

¹ This study was made in cooperation with the Klamath Forest Protective Association at Klamath Falls, Oreg. Without the yearly records of the association giving the location of felled trees, the study would have been impossible. The writer is indebted to J. F. Kimball, secretary-treasurer, and to H. H. Ogle, of the same association, for valuable assistance in obtaining the field data.

proximately 16,000,000 feet board measure, over an area roughly of 200,000 acres. Further work in the next three or four years will probably involve cutting an additional 20,000,000 feet of merchantable timber on adjoining areas. These trees must be left on the ground until such time as they can be reached by logging operations. The rate of deterioration of this felled timber then becomes of paramount importance. It is in connection with this project that the study reported here was made.

METHOD OF COLLECTING DATA.

Local control work has been carried on in this region for some years by the Klamath Forest Protective Association, and records of this association were available, giving the general location of trees felled yearly since 1915. From these records, felled trees were relocated and examined during November, 1921.

Each tree was opened up sufficiently with ax and saw to permit scaling in 16-foot logs with the Scribner decimal C scale, according to standard commercial practice. Logs two-thirds or more unmerchantable by volume were culled. Diameter measurements were taken to the nearest inch, and length measurements to the nearest tenth of a foot. The gross scale where given is the actual merchantable volume in the trees at the time of felling, determined when this study was made. In making the measurements of decay, the subsequent advance of decay present in the living tree at the time of felling was disregarded. In the region in which the trees were studied the decays in living yellow pine seem to advance very slowly or not at all after an infected tree is felled. Characteristically, western yellow pine is a sound species, and the normal loss through decay in stands of living trees does not exceed 2.5 per cent and may be much less. The only two kinds of decay found in the trees examined which were there at the time of felling were rots caused by the ring-scale fungus (*Trametes pini* (Thore) Fr.) and brown cubical butt-rot caused by the velvet-top fungus (*Polyporus schweinitzii* Fr.). Two trees had been infected with the first-named rot, with a slight loss resulting. Brown cubical butt-rot had also been present in two trees, but there was little indication left of the decayed wood, which had been almost completely destroyed by fire when the bark removed from the trees was burned.

Data were obtained on a total of 100 trees, all western yellow pine, near Bly, Klamath Falls, and Keno, in Klamath County, Oreg., at elevations around 6,000 feet above sea level. The site conditions were essentially the same for all the localities. These trees varied from 16 inches to 43 inches in diameter outside bark at stump height, and the usual stump height ranged from 2½ to 3 feet.

RATE OF DETERIORATION.

These felled trees deteriorate with extreme rapidity, far more rapidly than the casual observer is led to believe. The heat from burning the bark and from the sun's rays results in a pronounced drying of the outer sapwood to depths averaging one-half inch. This outer layer, being too dry to decay, remains hard and sound for several years, and if tested superficially leads to the belief that

the tree is sound throughout, when as a matter of fact it may be commercially a complete loss through decay. Table 1 shows the rate of deterioration.

TABLE 1.—Rate of deterioration of felled western yellow-pine trees in Klamath County, Oreg.

When cut.	Seasons of exposure.	Volume (board feet).			Percentage of cull.	Trees with merchantable volume.		Average diameter inside bark stump (inches).	Number of trees (basis).
		Gross.	Cull.	Net.		Number.	Percentage of total.		
1	2	3	4	5	6	7	8	9	10
April, 1921.....	1	6,400	810	5,590	13	6	100	24	6
December, 1920.....	1	11,350	2,060	9,290	18	12	100	23	12
February, 1920.....	2	11,610	7,360	4,250	63	11	79	23	14
November, 1919.....	2	8,080	6,120	1,960	76	6	75	21	8
Spring of 1919.....	3	15,870	12,900	2,970	81	10	62	24	16
Spring of 1918.....	4	2,650	1,790	860	68	3	100	23	3
April, 1917.....	5	35,510	28,960	6,550	82	7	44	31	16
Spring of 1916.....	6	13,270	12,060	1,210	91	2	14	23	14
Spring of 1915.....	7	11,470	10,710	760	93	1	9	25	11

In Table 1 the expression "seasons of exposure" means the number of growing seasons that have elapsed since the trees were felled. It is, of course, during the growing season that the greatest deterioration occurs, although loss continues throughout the year. This is shown by the fact that the trees cut in April, 1921, and exposed for one season show a loss of 13 per cent, while those cut in December, 1920, also exposed for one season but with four additional months in winter and early spring, show a loss of 18 per cent. The same relation holds for the trees exposed for two seasons but cut at different times.

The important feature of Table 1 is the enormous increase in the cull percentage after the first season. This increase is from 13 and 18 per cent for the first season to 63 and 76 per cent for the second season and is so great that from an economic standpoint felled trees must be utilized before they pass into the second season of exposure. This means that the bulk of the trees cut on a control project must be regarded as a loss, since it is at present commercially impossible so to adjust logging operations that trees scattered over a large area can be picked up in a single season.

After the second season deterioration increases steadily, until by the end of the seventh season there is little merchantable volume to be obtained, and this only in an occasional tree much larger than the average or with some other abnormal condition. For example, the merchantable volume in the trees cut in 1916 came from two trees only, as is shown in column 7 of Table 1. One of these was a large tree with a diameter inside bark at stump height of 37 inches, while the other, though 11 inches smaller in the same dimension, had an unusually resinous butt log. The 760 feet board measure in the 1915 trees came from the first three logs in a 43-inch tree.

The criticism may be made that Table 1 is based on insufficient data. An examination of the table will show that the trees are well

distributed by seasons of exposure except in the case of those cut in 1918, of which there are only three, all that could be obtained. The basis for this class is insufficient. The cull percentage shows a steady increase and the percentage of total trees with merchantable volume a steady decrease except in the 1918 trees. This points to a sufficient basis for the other classes. Then, too, during the course of the field work the similarity in condition between trees exposed for the same number of seasons was quite apparent.

Figure 1, which is a diagrammatic smoothed curve based on Table 1, illustrates the rate of deterioration of the down timber.

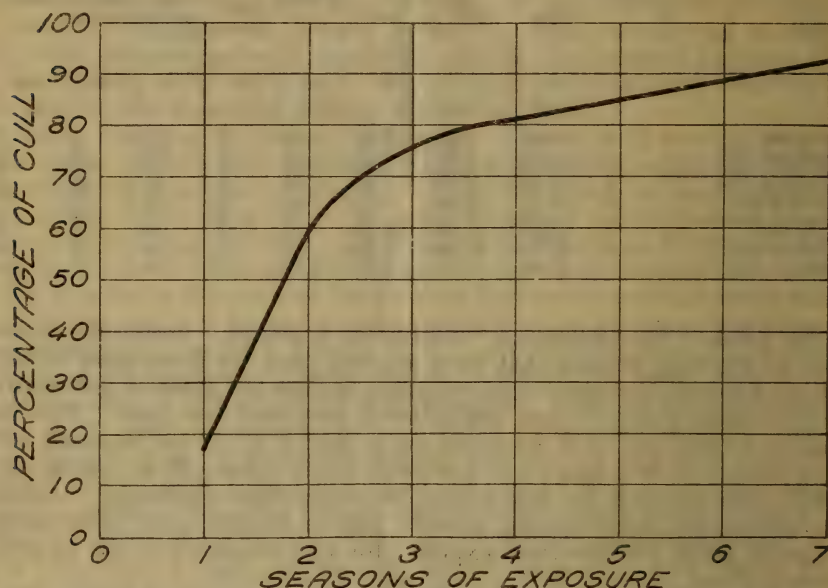


FIG. 1.—Diagrammatic smoothed curve, illustrating the rate of deterioration of felled western yellow pine.

CAUSES OF DETERIORATION.

In Table 1 sap-stain is not considered a defect. While this discoloration does degrade the lumber, discolored wood can still be used for a variety of purposes. In this region blue-stain caused by the fungus *Ceratostomella* sp. is most common, while a brown stain, of which the causal fungus is probably *Alternaria* sp.² is sometimes found. Staining is practically confined to the sapwood, rarely penetrating the heartwood. The extent of the stain in a tree is easily misjudged. As previously pointed out, there is a very dry outside layer of sapwood, too dry to stain, and a hasty examination may show bright wood, but deeper chopping will reveal the stain. By the end of the first season all the sapwood with the exception of the outer layer was heavily stained in the trees examined. In the upper portions of the trees, where the bark had been left on, this outer layer, since it had been kept moist, was also stained. The discoloration

²Hubert, Ernest E. Some wood stains and their causes. In *Hardwood Rec.*, v. 52, no. 11, p. 17-19, illus. 1922.

first began along the checks and then spread over the entire sapwood. If stained sapwood is considered a defect the loss for Table 1 after one season of exposure would amount to 78 per cent in the trees cut in April, 1921, and 67 per cent in the trees felled in December, 1920. This difference may be mere chance or it may indicate that the winter-felled trees for some unknown reason were less susceptible to discoloration by the time that climatic conditions in spring or summer favorable for staining arrived. Observations made on wind-thrown yellow pine in this region showed that heavy staining began in July. To avoid sap-stain as much as possible trees should be logged before that time.

That the principal causes of deterioration were relatively few and well defined is shown in Table 2.

The most important cause of cull in the trees exposed for one season was checks. Checks were confined mostly to the sapwood but in some cases extended deep into the heartwood.

TABLE 2.—*Causes of deterioration of felled yellow-pine trees in Klamath County, Oreg.*

When cut.	Seasons of exposure.	Cull (percentage of gross volume.)					
		Checks.	Sap-rot.	Heart-rot.	Broken in felling.	Burned.	Borers.
1	2	3	4	5	6	7	8
April, 1921.....	1	13.7					
December, 1920.....	1	16.2	1.5		0.2	0.3	
February, 1920.....	2	16.9	24.6			21.9	
November, 1919.....	2	11.5	57.3		3.7	3.2	
Spring of 1919.....	3		59.4	9.6	1.2	11.1	
Spring of 1918.....	4		63.4	4.2			
April, 1917.....	5	1.4	53.2	15.0	.5	9.6	1.9
Spring of 1916.....	6	3.9	63.7	14.1	.8	8.3	
Spring of 1915.....	7	.3	57.0	30.3		5.8	

Checking usually began and was most severe on the side of the trunk exposed to the direct rays of the sun. Exceptions to this rule were found where particularly intense heat had caused severe checking when the bark was burned. Normally the loss through checking in any one tree resulted from several or numerous checks, but in a very spiral grained tree a single deep check twisting around the tree sometimes caused all the loss. Considering column 3 of Table 2 it would seem that the loss through checking decreases with the length of exposure after the second season, while it is self-evident that this loss should increase slightly or remain about the same. The explanation is that as sap-rot becomes more severe the checks become obscure or disappear completely, and in scaling the loss from this source is then difficult to separate from that caused by sap-rot.

There was little sap-rot during the first season. In fact, the entire 170 board feet given in Table 2 were obtained from a single tree. But by the end of the second season the loss from this cause was heavy and continued so. After that time sap-rot was the most important factor in deterioration. In poles and young thrifty standards with wide sapwood, sap-rot by amounting to two-thirds or more of the gross volume often caused the loss of the entire tree. It fol-

lowed then that poles and young thrifty standards were subject to much more rapid deterioration than large trees, in which the ratio of sapwood to heartwood is inverted.

The upper side of the trunk decayed most rapidly, and the under side, the portion resting on the ground, much more slowly. This is probably explained by the retarding effect on the development of wood-destroying fungi from the excessive moisture content, lessened oxygen supply, and lower temperature of the wood of the under side as compared with the upper side. Decay first appeared along the checks, but avoided the dried outer layer of sapwood. Tongues of decay extended down from the ends of the checks. The decay then spread from the checks, finally involving the entire sapwood with the exception of the outer layer. Where the bark was left on in the top, the outer layer also decayed. Barking the tree somewhat retards decay, but not enough to be of practical importance, while on the other hand it promotes checking.

Generally it was impossible to determine the exact kind of decay in the different trees, but where this was done it was found that a white cellulose pocket rot³ caused by *Polyporus anceps* Pk. was most common, while a brown friable rot caused by the brown Lenzites (*Lenzites sepiaria* (Wulf.) Fr.) and a yellow-brown friable rot caused by *Fomes pinicola* (Fr.) Cke. occasionally occurred.

Heart-rot was not found in the trees until the third season of exposure. Decay first appeared as tongues running in from the sapwood or following in along deep checks. The white cellulose pocket rot was most common.

A negligible amount of loss resulted from breaks, usually in the top, when the trees were felled.

A more important source of cull was fire at the time the trees were felled and bucked. This sometimes did considerable damage. When the bark was burned, trees with open wounds were very likely to burn out along the scar and for some distance in advance. Fire scars, particularly in pitchy butts, were common starting points for destructive burns. Felling trees across one another or leaving limbs resting on the trunk resulted in additional loss from fire.

The loss caused by wood-boring insects was negligible. Ambrosia beetles did not attack the trunk from which the bark had been removed, while the round-headed and flat-headed borers did not attack the trees until sap-rot was well started.

From the foregoing discussion of Table 2 it is apparent that while checks caused some loss (and in a lesser degree so did fire), decay, particularly the very rapid decay of the sapwood, is responsible for most of the deterioration in these trees.

CONCLUSIONS.

The facts brought out in this bulletin should not be considered as of value for local application only. The climatic conditions of the Klamath Lake region, characterized by a small yearly precipitation, with a long summer drought, often beginning in the late spring and extending well into the fall, and low winter temperatures, are

³ This decay has also been called western red-rot. According to Dr. J. R. Weir, *Polyporus ellisianus* Murr. as known in the West is the same as *P. anceps* Pk.

exactly similar to those of a great part of the yellow-pine belt of eastern California, Oregon, and Washington, and not markedly at variance with conditions in other western yellow-pine regions in North America.

These results should prove generally applicable, with minor variations, on control projects in western yellow pine. Timber averaging smaller than that studied here will deteriorate more rapidly, while the deterioration in larger timber will, of course, be slower.

The felled and barked trees were completely sap-stained by the end of the first season of exposure. If sap-stain is considered a defect serious enough to make discolored wood worthless for lumber, there is such a large loss the first season that utilization by mid-summer is imperative. However, as a rule, stained lumber is only degraded and not culled.

Deterioration is very rapid and is chiefly caused by decay, particularly the very rapid decay of the sapwood, followed more slowly by the breaking down of the heartwood. The resulting loss is so high by the end of the second season that felled trees must be utilized by the beginning of the second season, or else the volume of merchantable wood obtained is so small as to be of little commercial importance. Consequently, the timber in most of the trees cut on a control project becomes a complete loss, since under present economic conditions it is usually not possible to utilize scattered trees over a large area within such a limited period of time.

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A STUDY OF DECAY IN DOUGLAS FIR IN THE PACIFIC NORTHWEST.

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IMPORTANCE OF DECAY IN DOUGLAS FIR.

Douglas fir is the most important timber tree in the Pacific Northwest, covering, as it does, the greater part of the foothills and lower slopes of the Cascade Mountains and the Coast Range in practically pure stands of great density. The stand of this species in Oregon and Washington is estimated at 505 billion feet (6, p. 23),¹ or nearly one-fourth of the remaining merchantable timber in the United States.

The loss through decay in Douglas fir in this region is very high. While some overmature stands are relatively sound a loss of 20 per cent in such stands is not uncommon. In certain cases the cull figure may reach 50 per cent or more, so high that in timber on difficult ground it becomes impossible to log at a profit. It is only in young stands of second growth that Douglas fir is uniformly sound. Plate I shows defective trees left uncut after logging in an overmature stand. In this instance about 25,000 feet board measure per acre was left standing. Where clear cutting is practiced numerous logs and entire trees remain on the ground after logging, absolutely worthless on account of decay. This is illustrated in Plate II. Practically all the large pieces were left because of rot.

Recognizing the importance of this question, foresters and lumbermen in the Douglas fir region have repeatedly felt the need for exact information on decay in Douglas fir. This bulletin presents observations by the writer and the results of a preliminary study.²

¹ The serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

² This study was made in the summer of 1917 under the direction of Dr. E. P. Meinecke. To him the writer is indebted for supervision and assistance throughout the course of the field work. The project was a cooperative one with the Forest Service of the United States Department of Agriculture, and acknowledgment is made to Forest Examiner F. B. Kellogg for his part in collecting the field data. A much more detailed study of decay in Douglas fir is now in progress, but will not be completed for several years.

METHOD OF COLLECTING DATA.

The trees selected for study were part of a defective, overmature stand of pure Douglas fir on the west slope of the Cascade Mountains at McCredie Hot Springs, above Oakridge, Lane County, Oreg. The area was at an elevation of about 2,000 feet above sea level, and the local topography was characterized by moderate slopes and almost level benches. The stand was quite typical of the bulk of the Douglas fir type on the west slope of the Cascade Mountains.

Each tree was felled with a stump height of $1\frac{1}{2}$ feet measured at a point halfway on the slope. The bole was then cut into 16-foot logs to an 8-inch top-diameter limit inside the bark. Complete measurements were then taken. Next, the logs were split open and any further data available recorded. In this way it was possible to study each tree very completely, particularly with reference to the character and distribution of decay. Volumes of the trees were worked up in both board and cubic feet. The board-foot volume included the merchantable portion of each tree from the stump height of $1\frac{1}{2}$ feet to a diameter limit of 8 inches inside bark. The 16-foot logs were scaled with the Scribner Decimal C scale and the volume of decay determined in accordance with the standard scaling practice of the Forest Service (5).

The cubic-foot volume included the contents of the entire stem from the ground level to the tip. In computing volumes the stump was considered as a cylinder, each 16-foot log as the frustum of a paraboloid, applying the Smalian formula (2, p. 161), the top (that is, the section from the 8-inch diameter inside bark to the tip) as a cone, and a broken section of the top which did not include the tip as the frustum of a cone. The actual cubic-foot volume of decay was computed by the same formulas.

A general idea of the size and age of the trees analyzed is given in Table 1.

TABLE 1.—*Size and age of Douglas fir trees studied.*

Age class.	Average age (years).	Average diameter breast high (inches).	Percentage of total volume.		Number of trees, basis.
			Cubic feet.	Board feet.	
41 to 60 years.....	59	9.5	0.04	0	1
61 to 80 years.....	68	12.1	.91	0.62	8
81 to 100 years.....	95	14.0	.53	.43	3
101 to 120 years.....	103	16.3	.75	.62	3
121 to 140 years.....	129	16.0	.15	.11	1
141 to 160 years.....					(1)
161 to 180 years.....					0
181 to 200 years.....	195	18.7	1.36	1.11	5
201 to 220 years.....	214	25.3	15.49	14.89	29
221 to 240 years.....	230	27.5	32.69	33.91	47
241 to 260 years.....	246	27.9	10.81	11.20	15
261 to 280 years.....	271	28.1	15.81	15.74	25
281 to 300 years.....	284	29.2	1.52	1.63	2
301 to 320 years.....	309	29.7	6.07	5.97	9
321 to 340 years.....	333	29.8	10.38	10.22	16
341 to 360 years.....	348	28.9	2.48	2.46	4
361 to 380 years.....	362	39.6	1.03	1.10	1
Combined.....	238	26.1			169

¹ One tree, too small to consider.

The trees studied were not clear cut from a given area, but average trees both sound and decayed were selected to obtain preliminary information on which an extensive study of decay in Douglas fir could be based. This will be brought out as the discussion proceeds.

In all 170 trees were felled, bucked up, split open, and studied. One of these was only 2 inches in diameter breast high, so it was dropped from consideration, leaving 169 trees with a total volume of 203,920 feet board measure and 33,703.12 cubic feet.

FUNGI CAUSING DECAY.

Four species of fungi are responsible for all but an infinitesimal portion of the decay in Douglas fir. They are the ring-scale fungus (*Trametes pini* (Thore) Fr.), the velvet-top fungus (*Polyporus schweinitzii* Fr.), the quinine fungus (*Fomes laricis* (Jacq.) Murr.), and the rose-colored Fomes (*Fomes roseus* (Alb. and Schw.) Cke.). The decays caused by these four wood-destroying fungi in living trees are confined to the heartwood.

The ring-scale fungus causes decay commonly known as conk-rot in this region (ring-scale or red-rot in the pine regions), in which the wood is riddled with small white pits or cavities, apparently separated by sound wood. This is shown in Plate III, Figure 1. In its incipient stages, before the appearance of the white pits, the decay appears as a pronounced reddish purple or olive-purple discoloration, often bounded by a narrow zone of pronounced red color. The sporophores, or conks, are very common in overmature Douglas fir stands. These fruiting bodies issue from the tree through knots and are perennial. They vary in size and in shape from bracketlike to hoof shaped. The upper side is a dull grayish or brownish black, rough, and with concentric furrows parallel to the light-brown margin. The under side is a grayish brown or rich brown color with large irregular pores. The substance or context of the sporophores is corky or punky. Plate IV shows the appearance of the sporophores on a living tree.

The velvet-top fungus causes a red-brown friable rot in the final stage. The incipient decay is very difficult to detect. It first becomes noticeable as a faint yellowing or browning of the normal heartwood, which still seems to be firm and hard but in reality is seriously weakened. The sporophores, or conks, of this wood destroyer appear either on the infected tree or on the ground near by and are annual. They are rather large, with a light-brown upper surface, an olive or dirty green under surface, and have a cheesy consistency when young, but when old and dry are a dark rusty brown and corky. Sporophores on the ground have a short thick stalk. Plate V, Figures 1 and 2, illustrate both sporophores and decay of this fungus.

The quinine fungus has a large, conspicuous, whitish perennial sporophore, not at all common on living trees. The substance of the sporophore is white, soft, and cheesy when young and rather crumbly and chalky when old and dry, with an exceedingly bitter taste. Hence the name. On the older sporophores the upper surface is rough and chalky white and brownish in color. The pores are small and regular. Plate VI, Figure 1, shows a sporophore. The typical decay is a crumbly brown rot easily recognizable by its mycelium felts or sheets (i. e., closely woven masses of fungus hyphæ). This characteristic is brought out in Plate VI, Figure 2. The incipient decay which appears as a faint brownish discoloration is not easy to recognize.

The sporophores of the rose-colored *Fomes* are easily recognized by the delicate rose color of the under surface. The pores are small. The upper surface is rough, hard, and black. This is illustrated in Plate III, Figure 2. The decay caused by this organism is a yellow-brown crumbly rot, with mycelium felts much less conspicuous than those of the quinine fungus. The incipient decay is indicated by a faint brownish color, the outer limit of which is sometimes marked by a zone of brownish green discoloration.

POSITION OF THE DECAYS IN THE TREE.

The decay caused by the ring-scale fungus and that caused by the quinine fungus are not confined to any one portion of the bole but commonly extend throughout the tree.

On the other hand, the decay caused by the velvet-top fungus is a typical butt-rot. Of the 70 infections of this decay in 68 trees, each separate focus of the rot in a tree being considered an infection, 94.3 per cent, or all but 4, were in the stump or butt log. The decay usually does not extend higher than the first 16-foot log. In 10 trees only did the decay go beyond the butt log, and the greatest upward extent in any one case was 37.4 feet above ground level. The average for all the butt infections was 10.41 feet above the ground. The measurements given include the incipient decay.

The decay caused by the rose-colored *Fomes* is usually confined to the upper portion of the tree in connection with dead tops, and often the rot does not extend into the merchantable portion of the infected tree. In all, there were 46 infections of this rot, and all but 9 of these were in the upper bole. Of those in the upper bole, 18, or almost 50 per cent, were in the top beyond the 8-inch diameter limit and caused no loss in merchantable volume.

For the sake of brevity in the remainder of this paper, the decays caused by these four fungi will be designated as follows:

Velvet-top fungus.....	red-brown butt-rot.
Ring-scale fungus.....	conk-rot.
Quinine fungus.....	brown trunk-rot.
Rose-colored <i>Fomes</i>	yellow-brown top-rot.

When used in tables the designations will be simply butt-rot, conk-rot, trunk-rot, and top-rot.

RELATIVE IMPORTANCE OF THE DECAYS.

Conk-rot is responsible for by far the greatest amount of cull in Douglas fir. In fact, if the species was free from this defect it would take its place with the pines as a sound tree. This is brought out in Table 2.

In considering Table 2 it must be remembered that it is not based on trees clear cut from a given area. Consequently the figures on the percentage of infected trees and volume of decay are not indicative of the actual loss through decay in stands of Douglas fir, but they do indicate the relation of the various decays. Under "unknown rots" are placed a number of small infections of decays whose cause could not be determined and one infection caused by *Ganoderma oregonense* Murr., which resulted in a slight loss.

Conk-rot stands out as the all-important cause of decay. The volume destroyed by this decay in comparison with the others is far

greater than the ratio of infected trees would indicate. For example, only about one-third more trees are infected with conk-rot than with red-brown butt-rot, yet the board-foot volume of decay is slightly more than 18 times as great. Conk-rot is usually quite extensive in an infected tree, particularly in the merchantable portion of the bole.

TABLE 2.—*Relative importance of the different kinds of decay in Douglas fir.*

Kinds of decay.	Volume of decay, percentage of gross volume.		Infected trees, percent- age of total.	Infections.			
	Board feet.	Cubic feet.		Number basis.	Percent- age of total.	Average volume.	
Conk-rot.....	38.4	22.5	61.0	118	41.6	663	64.2
Trunk-rot.....	2.7	1.3	5.9	15	5.3	369	28.7
Butt-rot.....	2.1	1.2	40.2	70	24.6	62	5.9
Top-rot.....	1.6	1.0	22.5	46	16.2	72	7.0
Unknown rots.....	.1	.1	18.9	35	12.3	4	1.0
Combined.....	44.9	26.1	87.6	284	.....	323	30.9

While only a few trees showed brown trunk-rot in comparison to those with red-brown butt-rot and yellow-brown top-rot, yet the volume of brown trunk-rot is greater than either of the others, particularly in board feet. This is due to the fact that brown trunk-rot when it does occur is quite likely to cause the loss of all or most of the merchantable portion of the affected tree. Yellow-brown top-rot and red-brown butt-rot, being localized, result in much less loss per tree, but make up for this in the many more trees with these decays. The greater loss through brown trunk-rot in board feet as compared to cubic feet in relation to red-brown butt-rot and yellow-brown top-rot is understood when it is remembered that the former is usually in the merchantable portion of the tree, while the latter two are often in the stump and top, which are not included in the board-foot volume but are figured in computing the cubic-foot volume.

Furthermore, red-brown butt-rot is of more importance than the figures would indicate, since seriously affected trees are quite subject to windfall, breaking off near the ground. Then, too, this decay destroys the valuable heartwood of the butt logs.

Of the total of 169 trees, 21 were free from decay, while in the remaining 148 there were 284 infections, or an average of 1.9 infections per infected tree. Some trees had as many as 6 individual infections. Again, in considering the infections conk-rot stands out both in the number of infections and particularly in the average volume of decay per infection. Trunk-rot has a high average volume of decay per infection, which shows again that this rot is of minor importance only because of the limited number of infections, but when a tree is once attacked destructive and extensive decay usually results.

MECHANICAL INJURIES.

Mechanical injuries on trees are of importance in that besides sometimes reducing the annual increment or causing an actual loss in merchantable volume from the mere presence of the injury they afford access to the heartwood of the tree for the spores of wood-destroying fungi.

Wounds in Douglas fir, though quite common, are mostly superficial and heal rather rapidly. Rapid healing is particularly the case in younger trees. Wounds as a rule callus very irregularly, and as a result it is usually difficult or impossible to determine the exact dates when scars were made and callused over by counting the annual rings. In this respect Douglas fir differs strikingly from the clear-cut, regular calluses characteristic of incense cedar and white fir. Furthermore, injuries in Douglas fir frequently result in the formation of prominent burls.

Of the trees studied, only 11 were entirely free from scars. The remaining 158 trees had 508 scars, open and healed over, an average of 3.2 wounds per tree. Table 3 shows the relative frequency of the various types of scars

TABLE 3.—Scars in Douglas fir.

Type of scar.	Number of scars, basis.			Percentage of total scars.	Type of scar.	Number of scars, basis.			Percentage of total scars.
	Open.	Healed over.	Total.			Open.	Healed over.	Total.	
Fire scars.....	43	237	280	55.1	Spike tops.....			10	2.0
Falling-tree scars.....	25	61	86	16.9	Broken tops.....			53	11.4
Lightning scars.....	11	38	49	9.6	Unknown scars.....	0		7	1.4
Sapsucker scars.....		9	10	2.0					
Blaze scars.....	1	0	1	.2	Total.....			508	
Frost cracks.....	0	7	7	1.4					

In Table 3 the healed-over, closed, or occluded scars are greatly in the majority. This indicates that the wounds were mostly superficial and that this tree species heals rapidly after wounding.

The predominance of fire scars is striking. While it was not possible to determine the years in which the fires occurred, for the reason stated previously, it was noticeable that most of the injuries of this nature had happened when the trees were relatively young—that is, below 20 inches diameter breast high, more or less. This coincides with our knowledge of fires in the Douglas fir region. In young stands fires which run over the surface of the ground injuring but not killing the trees are common, while in mature or overmature timber fires have a tendency to run through the crowns, killing all but scattered individuals outright.

Burls may form as the result of fire scars, but more common are swollen, or churn, butts as the result of severe scars. These churn butts extend usually from the ground level up the trunk slightly higher than the limit of the fire scar. Even though a fire scar has been healed over for a long time and there is no churn butt or burl to indicate its presence, it can often be detected by the variation in the appearance of the bark over the healed wound. This appearance is hard to describe, but not difficult to judge after a little experience.

Next in numerical importance to fire scars were wounds caused by falling trees. These, of course, are more common in mature and overmature stands than in second growth. Trees may die and ultimately the snags will fall, or again large trees with butt-rot are quite subject to windfall. Such trees on their way down strike others, breaking off the tops or limbs or bruising the trunks and knocking off pieces of bark. Falling-tree scars rarely extend deeply into the tree.

Lightning wounds occasionally occurred, although the Douglas fir region is not subject to severe lightning storms. Injury by sap-suckers was rare, and the few scars found were very superficial. These birds do not seem to select a single tree and attack it year after year, as they often do in other tree species. Frost cracks were not common. This was to be expected, since the Douglas fir region as a whole is not subject to sudden extreme variations of temperature from relatively warm to very cold.

There were 10 spike-topped trees. Half of these dead tops had been caused by lightning, while two of them resulted from falling trees.

On the other hand, trees with broken tops were not unusual. The most common cause of such injury was falling trees. This source accounted for 31 of the broken tops. Snow was responsible for 4 and lightning for 3, while the remaining 20 could not be determined. A load of ice or heavy wet snow is of more importance in causing broken tops than appears from these figures, but most of the damage occurs in young stands. According to observations of the writer and others, heavy snow or ice injury occurred about 1888³ in the immediate section where this study was made. The damage was very apparent from the number of broken tops, all having been made at the same time, in second-growth timber.

Broken tops require a long time to heal. Even after the volunteer top is well started the stub of the old top protrudes, and when this is finally grown over a slight crook still remains in the bole, which does not entirely disappear for years.

In considering the data presented, it may appear from the total of 508 scars on 158 trees that the trees were subject to excessive injury. It must be remembered that most of the wounds were superficial. Then, too, several small scars on a single tree might be made by the same agent. For example, one fire or one lightning stroke can readily cause several scars on a tree. Owing to the impossibility of determining with any accuracy the dates of injury in Douglas fir, it was necessary to consider each scar, with a few exceptions, as separate and distinct.

ENTRANCE OF THE DECAYS.

The wind-blown spores from sporophores of wood-destroying fungi attacking the heartwood of living trees must light on exposed dead wood in order to cause infection. But the type of infection court varies with different species of decay, and it is of importance to determine the common means of entrance in each case, since in so far as the infections occur through controllable mechanical injuries there is a possibility of reducing the amount of loss.

Table 4 shows the points of entrance for conk-rot. From this table it can be seen that knots or branch stubs are responsible for the major portion of the infections, and, what is far more important, all but an infinitesimal portion of the total volume of conk-rot resulted from these infections.

The infections of brown trunk-rot both numerically and in the resulting volume of decay were rather more evenly distributed, as can be seen from Table 5; but here again knots predominate.

³ This date is from an unpublished record furnished by the Forest Service.

TABLE 4.—*Infection court of conk-rot in Douglas fir.*

Infection court.	Infections.					
	Number, basis.	Percentage of total.			Average volume.	
		Number.	Volume.			
				Board feet.	Cubic feet.	Board feet.
Knots.....	98	83.0	99.62	99.48	706	77.0
Fire scars.....	10	8.5	.04	.03	3	.2
Falling-tree wounds.....	3	2.5	0	.05	0	1.4
Lightning scars.....	4	3.4	.34	.43	68	8.2
Dead tops.....	1	.9	0	0	0	0
Unknown scars.....	2	1.7	0	0	0	0

TABLE 5.—*Infection court of trunk-rot in Douglas fir.*

Infection court.	Infections.					
	Number, basis.	Percentage of total.			Average volume.	
		Number.	Volume.			
				Board feet.	Cubic feet.	Board feet.
Knots	7	46.7	44.6	46.1	353	28.4
Fire scars	2	13.3	0	0	0	0
Falling-tree scars	4	26.7	30.0	26.9	415	29.0
Lightning scars	2	13.3	25.4	26.9	705	58.0

Table 6 brings out the relation between fire and red-brown butt-rot. The major portion of the infections entered through fire scars, and the resulting volume of decay was proportionately much higher. This butt-rot also attacks the roots and can probably be spread by the contact of a diseased root with a sound one. About 11 per cent of the volume of rot is apparently traceable to this method of infection. Besides these two the other infection courts are of no importance.

TABLE 6.—*Infection court of butt-rot in Douglas fir.*

Infection court.	Infections.					
	Number, basis.	Percentage of total.			Average volume.	
		Number.	Volume.			
				Board feet.	Cubic feet.	Board feet.
Knots.....	1	1.4	1.4	0.5	60	2.0
Fire scars.....	41	58.6	78.2	79.1	83	3.0
Falling-tree scars.....	4	5.7	3.7	5.0	40	5.2
Lightning scars.....	4	5.7	2.5	1.8	28	1.8
Roots.....	16	22.9	10.8	11.5	29	3.6
Unknown scars.....	4	5.7	3.4	2.1	38	2.2

Yellow-brown top-rot, true to its name, in Table 7 shows the greatest number of infections entering through dead tops, which include broken and spike tops. Knots, though with fewer infections, were responsible for a greater volume of decay, since such infections usually occurred lower down on the bole where there was more heartwood for the fungus to work on than was the case when the wood destroyer entered through a dead top. The large volume of decay the cause of which is recorded as "unknown" resulted from an extensive infection which could not be traced to its source.

TABLE 7.—*Infection court of yellow-brown top-rot in Douglas fir.*

Infection court.	Infections.					
	Number, basis.	Percentage of total.			Average volume.	
		Number.	Volume.			
				Board feet.	Cubic feet.	Board feet.
Knots.....	12	26.1	35.8	35.7	98	9.6
Fire scars.....	2	4.3	8.2	6.6	135	10.6
Falling-tree scars.....	7	15.2	7.0	1.9	33	.9
Lightning scars.....	5	10.9	15.4	15.0	102	9.7
Dead tops.....	18	39.1	17.0	23.8	31	4.3
Unknown.....	2	4.3	16.7	17.0	275	27.5

Table 8 shows the infection courts of the unknown decays. Some of these were undoubtedly infections of the four common rots, but were abnormal or so small that they could not be accurately identified.

TABLE 8.—*Infection court of unknown rots in Douglas fir.*

Infection court.	Infections.					
	Number, basis.	Percentage of total.			Average volume.	
		Number.	Volume.			
			Board feet.	Cubic feet.	Board feet.	Cubic feet.
Knots.....	5	14.3	0	0	0	0
Fire scars.....	12	34.3	80.0	62.5	10	1.8
Lightning scars.....	4	11.4	20.0	8.8	8	.8
Dead tops.....	11	31.4	0	20.8	0	.6
Roots.....	3	8.6	0	7.8	0	.9

In Table 9 the data in Tables 4 to 8, inclusive, have been combined. Knots were responsible for the greatest number of infections and a proportionately greater loss through decay.

Of all the infection courts fire scars, which were only responsible for 4.2 per cent of the total rot volume, are the only factors that can be directly controlled. With the increase of efficiency in fire-protection methods, injury from fires is being steadily reduced. But the other 95.8 per cent of the decay is traceable to sources that can not be controlled. Knots, falling trees, lightning, and snow or ice will

be present in Douglas fir stands in the future, no matter how well regulated. Consequently, the reduction in the quantity of rot in Douglas fir by a reduction in the scars caused by controllable mechanical injuries can amount to little.

TABLE 9.—*Infection court of combined decays in Douglas fir.*

Infection court.	Infections.					
	Number, basis.	Percentage of total.			Average volume.	
		Number.	Volume.			
			Board feet.	Cubic feet.	Board feet.	Cubic feet.
Knots.....	123	43.3	89.2	89.2	664	63.9
Fire scars.....	67	23.6	4.2	4.2	57	5.5
Falling-tree scars.....	18	6.3	2.2	1.7	114	8.2
Lightning scars.....	19	6.7	2.5	2.4	123	11.5
Dead tops.....	30	10.6	.6	1.0	19	2.8
Roots.....	19	6.7	.5	.6	25	2.6
Unknown scars.....	8	2.8	.8	.7	88	8.0

While it is true that infection courts resulting from all mechanical injuries are of little importance in the total volume of decay produced as compared to knots or branch stubs, it is of academic interest to determine the kind of scar most susceptible to infection in the trees studied. This is brought out in Table 10.

TABLE 10.—*Susceptibility to infection of various scars in Douglas fir.*

Type of scar.	Number of scars.	Scars infected.		Type of scar.	Number of scars.	Scars infected.	
		Number.	Per cent.			Number.	Per cent.
Fire scars.....	280	67	23.9	Spike tops.....	68	30	44.1
Falling-tree scars.....	86	18	20.9	Broken tops.....		7	100
Lightning scars.....	49	19	38.8	Unknown scars.....			
Sapsucker scars.....	10	0	0	Total.....	508	141	28.0
Blaze scars.....	1	0	0				
Frost cracks.....	7	0	0				

Dead tops, which include spike-tops and broken tops, followed by lightning scars, were most susceptible to infection, according to Table 10.

INDICATIONS OF DECAY IN LIVING TREES.

Recognition of the indications of decay in standing Douglas fir or in logs is of the greatest importance from a practical standpoint. A comparison of the cruise and actual cut on many operations in overmature decadent timber brings this out forcibly. At present there is a great deal of confusion and misinformation among foresters and lumbermen in regard to the detection of decay in living trees, and the specter of "hidden defect" assumes unnecessary proportions. In fact, decay in Douglas fir is more easily detected than in most species subject to a large amount of rot.



DEFECTIVE DOUGLAS FIRS LEFT STANDING AFTER LOGGING.

The principal defect is decay caused by the ring-scale fungus.



**A PRACTICALLY PURE STAND OF OVERMATURE DOUGLAS FIR AFTER
LOGGING.**

Nearly all the large pieces were left because of rot, principally decay caused by the ring-scale fungus. (Photographed by D. C. Ingram.)

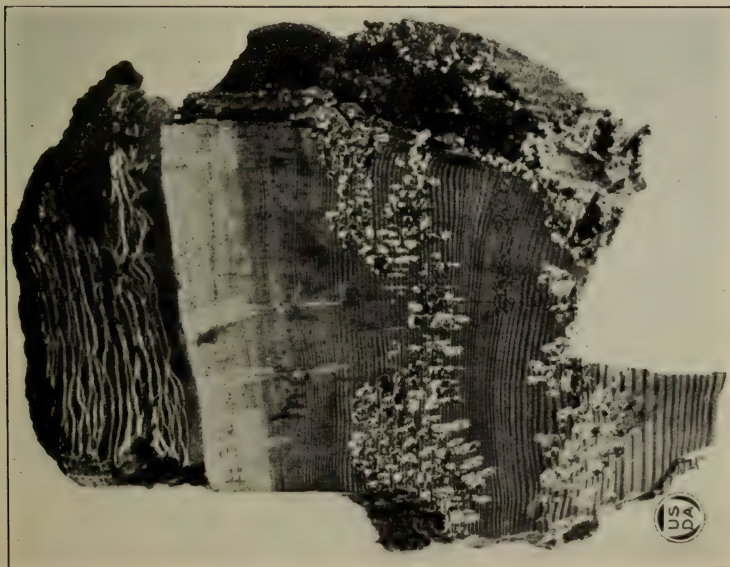
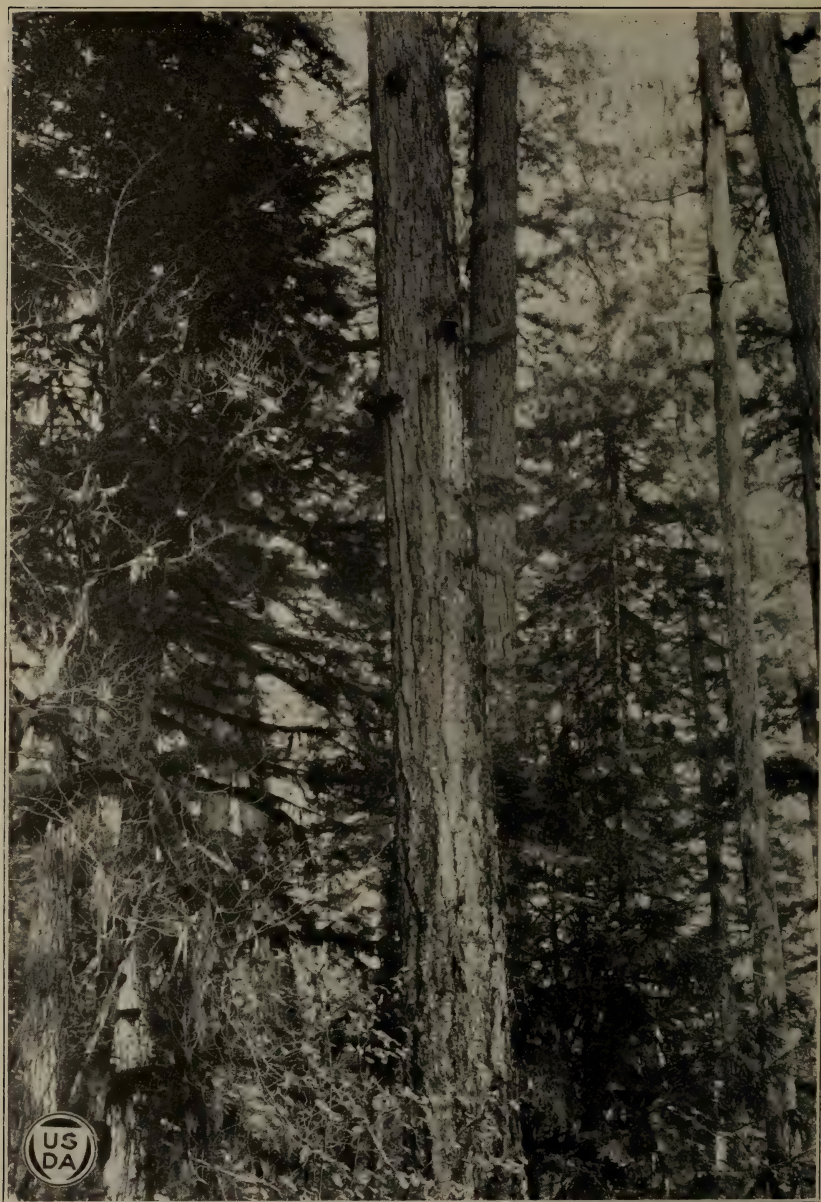


FIG. 1.—CONK-ROT CAUSED BY RING-SCALE FUNGUS.
This illustrates the typical stage of the decay. In its incipient stages the rot is indicated by a reddish purple discoloration.



FIG. 2.—CROSS SECTION OF A DOUGLAS FIR TOP.
This shows the upper surface of a sporophore of the rose-colored fungus and the yellow-brown rot caused by this fungus.



SPOROPOHORES OF THE RING-SCALE FUNGUS, INDICATING CONK-ROT IN THE
HEARTWOOD OF THE TREE.

(Photographed by G. G. Hedgcock.)

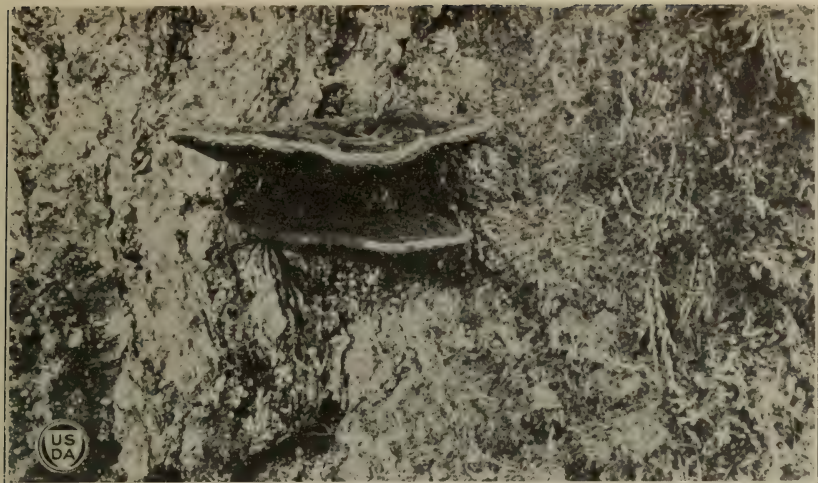


FIG. 1.—SPOROPOHORES OF THE VELVET-TOP FUNGUS ON THE BUTT OF A LIVING DOUGLAS FIR.

These sporophores indicate red-brown butt-rot in the tree. (Photographed by G. G. Hedgcock.)

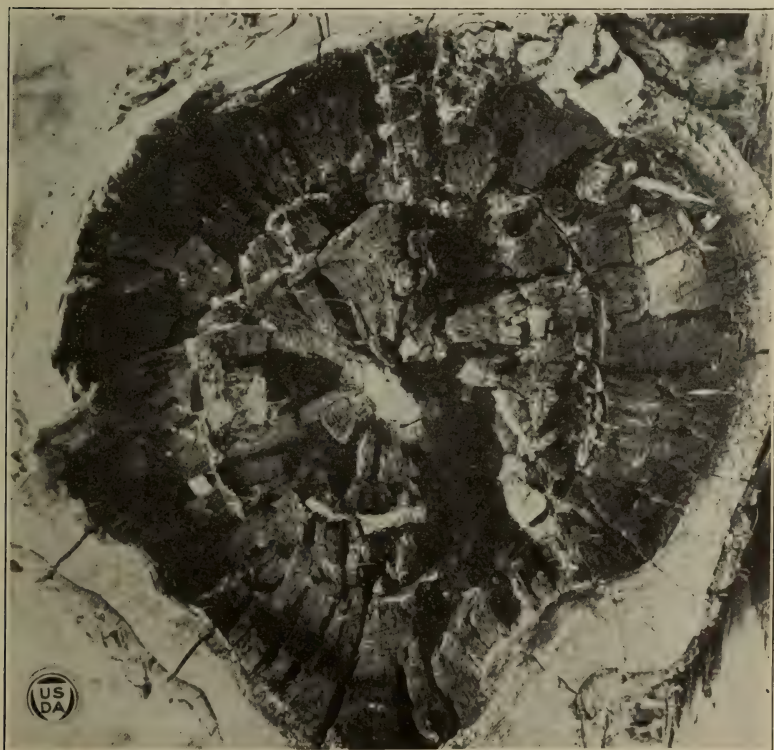


FIG. 2.—RED-BROWN BUTT-ROT CAUSED BY THE VELVET-TOP FUNGUS.

Only a thin shell of sapwood remains. Trees so badly decayed are subject to windfall, particularly if the rot extends into the roots. (Photographed by G. G. Hedgcock.)

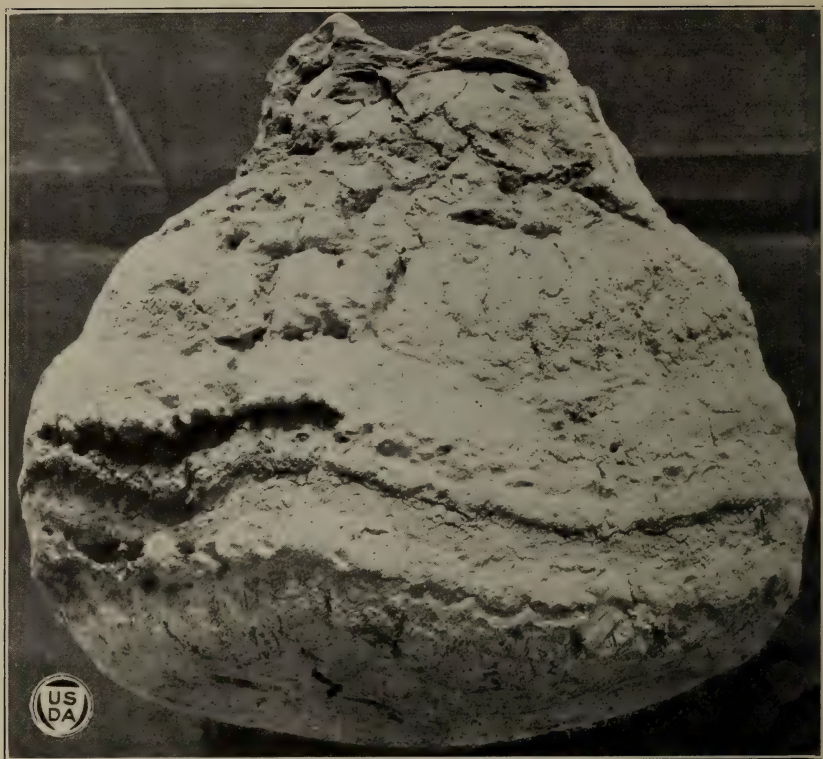


FIG. 1.—SPOROPHORE OF THE QUININE FUNGUS.

These conspicuous whitish fruiting bodies are not common on living trees, but are found more often on dead down timber. The sporophore has a very bitter taste.



FIG. 2.—BROWN TRUNK-ROT CAUSED BY THE QUININE FUNGUS.

The decay is usually extensive in an infected tree



BURL ON A DOUGLAS FIR LEFT STANDING ON A CUT-OVER AREA.

Because of the burl the tree was thought to be badly decayed. Burls do not indicate decay
Compare with Plate VIII.



SWOLLEN KNOTS OR BLIND CONKS ON DOUGLAS FIR.

These indicate conk-rot in the tree. Compare with Plate VII.

DEAD LIMBS.

Large trees with many dead limbs in the lower crown are no more likely to be decayed than a normal tree. Such "wolf trees," as they are known to the forester, merely grew faster than their neighbors, and their branches did not die so soon through lack of light; consequently it requires a longer time for these large limbs to drop off and for the branch stub to heal over.

BRANCH FANS.

Groups of branches, radiating like a fan from one point, are not uncommon on Douglas fir. These branch fans have been considered by some persons as indications of decay. A little thought will show that this is not within the realm of probability. That decay in the dead heartwood could directly affect the vital growing portion of the trunk of a tree in such a way as to cause abnormal branching is directly contrary to all our knowledge of growth and development of trees. In all, these branch fans were found on 32 trees, varying from 1 to 15 on a single tree, with an average of 4.4. Of these 32 trees, 2 were free from decay, while in 19 the infections were very light, rarely causing a loss of more than 10 board feet, and the branch fans were not on the same portion of the trunk as the decay. There was a considerable volume of decay in each of the 11 remaining trees, but in 7 of these the decay was in the lower or middle portion of the trunk, while the branch fans were above it in the crown. In only 4 trees were part or all of the branch fans found on the decayed section of the trunk. These figures indicate the complete lack of even an empirical relation between branch fans and decay.

BURLS.

Douglas fir when bruised is subject to burls at the point of injury, but it is questionable whether or not all burls are caused by wounding. Such burls are a disorganized mass of wood tissue with a gnarled or twisted grain. This formation is a direct response to the irritation caused by the injury. Burls are often considered to indicate decay. Plate VII shows a tree left uncut on a logging operation because it was presumed from the presence of the burl that the tree was badly decayed. Data showing the relation of decay to burls in the trees studied are presented in Table 11. The number of burls to the tree varied from 1 to 20, with an average of 3.6.

TABLE 11.—*Relation of burls to decay in Douglas fir.*

Character of data.	Number.	Per cent.
Trees with burls.....	43	.....
Trees with burls and no decay.....	6	14.0
Trees with burls and decay on different sections of the trunk.....	19	44.2
Trees with burls and decay on the same section of the trunk.....	18	41.9

Analysis of the data in Table 11 demonstrates that the presence of burls does not mean decay in the tree. Of the trees with burls 14 per cent were free from decay, while in 44.2 per cent the rot and burls did not occupy the same section of the bole. Burls on the butt of the tree, however, are sometimes an indication of decay, since burls in this position often result from wounding by fire, and fire scars are quite commonly infected with red-brown butt-rot.

CONK-ROT.

The decay causing by far the greatest loss in Douglas fir is relatively easy to detect. Sporophores of this decay occur abundantly. This is indicated by the local name of conk-rot used in the Pacific Northwest. Lumbermen observed the unusually common occurrence of sporophores, or "conks," on infected trees, as compared to those with other decays, and the name followed. The prolific development of sporophores is shown by the fact that of 83 trees with sporophores there was an average of 14.4 per tree, or a total of 1,196. Considering all infections both with and without sporophores there was an average of 10.1 sporophores per infection, or 1 for every 6.34 cubic feet of conk-rot in the trees and 1 for every 65 board feet.

It is of interest to consider the orientation of these sporophores. Möller (4), working with the same fungus, found 89.4 per cent of the sporophores on the westerly side of the trees. He explained this by the facts that the prevailing winds were from the west and the trees were most strongly struck by rain on the west side, and consequently the branch stubs (a very common point of infection) were more moist on that side. Weir and Hubert (7, p. 30), in their work with the Indian-paint fungus (*Echinodontium tinctorium* E. and E.) on western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), found that most of the sporophores had a northwest to north-northeast orientation. The same workers (8, p. 18), studying conk-rot in western white pine (*Pinus monticola* Doug.), found the largest percentage of the sporophores developed on the west side of the tree, with the smallest percentage on the southeast side. Table 12 shows the orientation of the sporophores on the trees studied.

TABLE 12.—Orientation of sporophores of conk-rot in Douglas fir.

Character of data.	Orientation of sporophores.							
	NW.	N.	NE.	E.	SE.	S.	SW.	W.
Number of sporophores.....	212	291	202	91	144	77	96	79
Percentage of total	17.8	24.4	17.0	7.6	12.1	6.5	8.1	6.6

The largest percentage of sporophores occurred on the north side of the trees and the smallest percentage on the south side. Adding the sporophores on the north, northwest, and northeast it is seen that 59.2 per cent were in the northerly grouping. Following this system gives 36.7 per cent easterly, 26.7 per cent southerly, and 32.5 per cent westerly. The northerly direction clearly predominates. This is logically explained by the fact that there is less light on the northerly side and consequently more moisture, particularly during the growing season, which in this region is a long dry period interrupted by occasional thundershowers of brief duration. Conditions on the northerly side of the trees are therefore more favorable for infection and the subsequent development of sporophores.

As a rule very little rot develops in a tree before a sporophore appears, or if not a sporophore at least a swollen knot, or "blind conk," as it is colloquially termed. The sporophores can not penetrate the unbroken bark and issue only through knots or branch

stubs not yet occluded. A swollen knot is the initial stage of a sporophore in which the substance forming the conk is growing out through a knot and forcing out the bark. The pressure may also cause an increase in the width of the sapwood immediately around the knot, which accentuates the swelling. Swollen knots are illustrated in Plate VIII. A swollen knot is just as good an indication of the presence of decay as a sporophore. Often the sporophore never develops beyond this stage, remaining abortive. Chopping into one of these knots reveals a brown, soft, corky or punky context, the same as in a fully developed sporophore. Plate III, Figure 1, shows a section through part of a decayed knot.

The effect of fire on sporophores or swollen knots is striking. When mature timber is swept by fire, the flames running along the trunk of the tree can not burn off the thick bark. However, the corky context of the sporophores and decayed knots burns readily, and this results in rounded, blackened hollows extending for several inches into the tree where the fire has burned out the decayed knots. This makes it possible to judge in a measure the extent of conk-rot in recently fire-killed Douglas fir.

That the development of swollen knots and sporophores follows rather closely the progress of conk-rot in the heartwood is brought out in Table 13.

TABLE 13.—*Relation of sporophores and swollen knots to conk-rot in Douglas fir.*

Decay.	Infections.		Volume of decay.					
	Num- ber, basis.	Per- cent- age of total.	Percentage of total.				Average per infection.	
			Gross.		Of conk-rot.			
			Board feet.	Cubic feet.	Board feet.	Cubic feet.	Board feet.	Cubic feet.
With sporophores.....	96	81.4	36.83	21.71	95.94	96.51	782	76.2
Without sporophores.....	22	18.6	1.56	.78	4.06	3.49	144	12.0
With swollen knots.....	108	91.5	38.39	22.49	99.95	99.97	725	70.2
Without swollen knots.....	10	8.5	.01	.01	.04	.03	3	.2

Table 13 shows that while there was a noticeable percentage of the infections which did not develop sporophores, these infections were very small, as is indicated by the volume percentages and the average volume per infection. The relation is even more striking with swollen knots, where the volume percentages and the average volume per infection of those infections without swollen knots is so small as to be negligible.

This means, then, that it is possible to pick out rather accurately the trees in a stand affected with conk-rot. When high up in a tree among the branches swollen knots, or even sporophores, are not easily seen, but if overlooked there it does not make so much difference in the accuracy of an estimate, since the volume of the top logs is relatively insignificant in the total.

EXTENT OF CONK-ROT.

It is not only possible to pick out the decayed trees, but it is also feasible to judge with some exactness the normal extent of conk-rot.

In the trees studied it was found that the average extent of decay, including typical and incipient decay, above the highest sporophore was 20.1 feet. This was based on 83 infections. In two infections the decay ended at the height of the top sporophore, and in one tree the rot extended for 61 feet above the highest sporophore. When the downward extent of conk-rot below the lowest sporophore was considered, it was necessary to discard those infections in which the decay extended into the stump. Based on only 33 infections, the average downward extent was 13.9 feet. The average of both upward and downward combined was 18.3 feet.

The same figures for the highest and lowest swollen knots were as follows: Upward extent, 9.5 feet, based on 93 infections; downward extent, 9.2 feet based on 41 infections; combined average, 9.4 feet. In one tree the rot extended for 45.2 feet below the lowest swollen knot. This difference in the extent of decay beyond sporophores as compared to swollen knots is due to the fact that the swollen knot in many instances is the initial stage in the development of a normal sporophore, and consequently by the time a sporophore appears the decay has been in the tree longer and has progressed farther than at the formation of a swollen knot.

These data mean, then, that it is possible to approximate the volume of conk-rot in defective trees when cruising. The figures, of course, should not be applied to an individual tree as such, but should be used in estimating the individual components of a stand in order to secure an accurate figure on the total loss through conk-rot. In actual practice the writer would use 20 feet as the upward or downward extent of decay beyond the highest or lowest sporophore and 10 feet as the figure for swollen knots. In other words, in the case of a decayed tree with sporophores the trunk would be considered unmerchantable from a point 20 feet below the lowest sporophore to a point 20 feet above the highest sporophore, while for swollen knots the distance would be reduced to 10 feet below and above. These figures are easy to remember and have checked well with the writer's observations since this study was made; but for greater accuracy in any given locality it is well to study felled trees and watch long logs through the mill, so that these limits can be corrected to fit local conditions.

RED-BROWN BUTT-ROT.

Sporophores are, of course, the best indication of decay. The sporophores of red-brown butt-rot being annual are not common except in favorable seasons for their development, but can always be found now and then in a locality where the trees are affected. However, the best clue is fire scars. Noticeably fire-scarred trees are commonly infected with this decay. Of the 125 trees with fire scars that were studied, 41, or 33 per cent, were infected with red-brown butt-rot. Healed fire scars can often be detected by a variation in the appearance of the bark over the wound or by swollen or churn butts. There are no swollen knots with this decay.

BROWN TRUNK-ROT.

Brown trunk-rot is rather hard to detect. Swollen knots are not formed. Sporophores are rare on living trees, but when they do occur they are very conspicuous and not readily overlooked.

Furthermore, observation shows that they indicate extensive decay in the tree. Only one tree studied had sporophores of this rot, and the decay volume in cubic feet was 31 per cent and in board feet 74 per cent of the gross volume of the tree. But the total loss caused by this decay was trifling. (See Table 2.)

YELLOW-BROWN TOP-ROT.

Yellow-brown top-rot also is rather hard to judge. Swollen knots do not accompany the decay. Sporophores are not uncommon, particularly with the more extensive infections. In the trees studied, seven infections, which resulted in 42 per cent of the cubic-foot volume and 41 per cent of the board-foot volume of yellow-brown top-rot, had developed sporophores. However, the sporophores are commonly so high up in the trees that they are easily overlooked and, in fact, are often completely hidden by the branches. Broken or spike tops commonly indicate infection (see Table 7). The aggregate loss caused by this decay is small.

INDICATIONS OF DECAY IN FELLED TIMBER.

The estimate of the extent of defect in logs or felled timber is much easier than in standing trees. The red-brown butt-rot is revealed in the butt cut, and its upward extent can be more closely approximated. Knots can be tested carefully for signs of rot, and if the timber has been bucked the ends of the logs can be examined for typical decay or the discolorations caused by incipient decay. However, if the logs have been exposed to the weather for several months these discolorations fade and can not be seen.

It is not at all difficult to judge quite accurately the extent of conk-rot in felled Douglas fir by chopping into the knots to reveal the brown corky context of the abortive sporophore.

EXTENT OF INCIPIENT DECAY.

A knowledge of the vertical extent of incipient decay, which is the term used to designate the early stages of rot, beyond the typical decay or well-advanced rot is of practical value. In some infections the incipient decay may end with the typical decay and in other cases extend many feet beyond it. The horizontal or radial extent normally amounts to only a few inches. Incipient decay, which is usually indicated by a discoloration of infected wood, in some cases pronounced and in others so faint as to be practically invisible, is not always easy to detect. Affected wood in a casual examination seems to be firm and strong. Consequently, it is the rule rather than the exception in the lumber trade to include incipient decay with sound lumber.

Wood is weakened by incipient decay, the degree depending on the stage of the rot and also on the species of fungus at work. Tests (3) on Douglas fir with incipient decay of conk-rot showed that the wood was apparently not weakened, but pieces with incipient decay of red-brown butt-rot and brown trunk-rot, to which general type of decay yellow-brown top-rot also belongs, were much reduced in strength. Furthermore, if infected material is merely air dried, the hyphæ may remain dormant, ready to continue to decay the wood again if suitable conditions arise. Hence, wood with incipient decay

should be excluded from all lumber to be used for purposes requiring strength and durability.

The incipient stage of conk-rot is often quite extensive. In one tree this stage of decay extended for 29.6 feet vertically in the heartwood beyond the typical decay, while in several infections this figure ranged from 10 to 20 feet. The average extent upward of incipient decay beyond the typical decay was 3.3 feet and the average extent downward was 4 feet. The significance of this difference will be touched upon later. The average extent both up and down was 3.5 feet, based on 145 measurements.

Red-brown butt-rot is less variable in respect to the extent of incipient decay. The greatest extent found was 8.4 feet, while the average based on 44 measurements was 1.95 feet. This average is based on measurements of upward extent only, since most of the infections began in the stump or extended into it and no downward measurements were possible.

Only meager data were available on brown trunk-rot. Based on 13 measurements the upward extent of the incipient decay was found to be 3.5 feet, while the downward extent was 3.6 feet. The combined average was 3.6 feet. The extreme extent was 8.5 feet above typical decay.

The incipient decay of yellow-brown top-rot had an average extent upward of 2.2 feet and downward of 3.8 feet, while the combined average was 3.1 feet, based on 58 measurements. In one tree incipient decay extended up beyond typical decay for a distance of 25.4 feet.

From the foregoing it can be seen that in all three of the rots in which it was possible to make a comparison between the upward and downward extent of incipient decay the downward extent exceeded the upward on the average, and the difference is most striking in yellow-brown top-rot, where most of the infections occur in the upper part of the bole. This difference is probably explained by the well-known fact that older trees are much more subject to decay than younger ones, and therefore it follows that older heartwood is more susceptible than younger. As the fungus progresses downward in the heartwood of a tree it encounters wood gradually increasing in age and easier to decay, while as it moves upward younger wood which offers more resistance is continually invaded, decreasing the extent of both typical and incipient decay. This tendency for decay to work more rapidly downward than upward is in keeping with other observations (*l*, p. 21).

The figures presented on the extent of incipient decay show that this is quite variable and indicate the need for careful inspection to eliminate this type of defect from timbers where durability and strength are a prerequisite.

SUMMARY.

The four principal decays in Douglas fir are conk-rot caused by the ring-scale fungus (*Trametes pini*), red-brown butt-rot caused by the velvet-top fungus (*Polyporus schweinitzii*), brown trunk-rot caused by the quinine fungus (*Fomes laricis*), and yellow-brown top-rot caused by the rose-colored Fomes (*Fomes roseus*). Conk-rot and brown trunk-rot usually occur in the body of the trunk, red-brown butt-rot is commonly confined to the stump and first log, while yellow-

brown top-rot usually occurs in the upper bole or top. Conk-rot causes by far the greatest volume of decay. The other three rots are of relatively minor importance, except that red-brown butt-rot predisposes an infected tree to windfall.

Douglas fir is subject to wounding throughout its life and particularly to injury by fire during its earlier years. On the whole, wounds in Douglas fir are mostly superficial, and this tree species heals rapidly after wounding. Scars callus very irregularly, and it is usually difficult or impossible to determine the exact dates when scars were made.

Mechanical injuries are of little importance in relation to the entrance of decay. Knots were responsible for nearly 90 per cent of the volume of all decay in the trees studied. Fire scars were the entrance point for 4 per cent, and the remaining 6 per cent came in through other scars. Fire is the only factor which is controllable, so there can be but little reduction in the extent of decay in future stands by a reduction in the scars caused by controllable mechanical injuries.

Recognition of the indications of decay in standing or felled timber is of the greatest importance from a practical standpoint, yet this is little understood. Branch fans, dead limbs, or burls do not indicate decay. Sporophores and swollen knots which develop prolifically indicate the presence of conk-rot. After a stand has been fire swept, burned-out hollows show where there were sporophores and swollen knots. It is also possible to approximate with some accuracy the volume of the decay. Conk-rot, on the average, extended approximately 20 feet in the trunk beyond the highest or lowest sporophore and 10 feet beyond the highest or lowest swollen knot. Sporophores of red-brown butt-rot are not common. However, the relative frequency of fire scars indicates somewhat the relative amount of this decay. Churn butts often denote old fire scars. Brown trunk-rot is rather difficult to detect in standing trees, but the loss caused by this decay is insignificant. This also applies to yellow-brown top-rot.

Figures on the different rots, giving the extent of incipient decay beyond typical decay, show that this is rather variable, thus requiring careful inspection to obviate the inclusion of wood with this type of defect in timbers selected for durability and strength.

OUTLOOK.

The work on which the preceding discussion is based is merely preliminary. More extensive studies are needed to bring out new facts and develop still further those already brought out. This should aid materially in placing the estimating of Douglas-fir timber on a more exact basis.

The biggest problems remain unsolved. Our half-formulated ideas of control of decay in Douglas fir are based on observation without a sound backing of exact data. Furthermore, while it is a well-established fact that young stands or second growth are relatively immune from decay, it is not yet determined at what age in the life of the stand this immunity ceases and the trees become subject to extensive decay. Establishing this age will enable us in the future

to cut stands before there is any real loss and at the same time permit the trees to attain the maximum size.

Equally important is the periodic rate of increase in the loss through decay after the above age has been passed. Such information is of the highest value to organizations holding extensive stands of mature or overmature timber, enabling them to estimate the loss in their holdings and adapt plans accordingly. But these questions can only be answered by the study of all the trees felled and left standing on a wide range of plats in stands of different ages and conditions selected on logging operations throughout the Douglas-fir region of the Pacific Northwest.

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WHITE-PINE BLISTER RUST IN WESTERN EUROPE.

By W. STUART MOIR, *Assistant in White-Pine Blister-Rust Eradication, Office of Blister-Rust Control, Bureau of Plant Industry.*

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INTRODUCTION.

Following the outbreak of the white-pine blister rust in the north-eastern United States and in Ontario, Canada, foresters and pathologists sought a method of combat, and to this end European literature was scanned for assistance (40)¹. The European scientists who studied the causal fungus (*Cronartium ribicola* Fischer) had confined their research almost exclusively to its biology. Their investigations as summarized in literature contain many suggestions for combating the disease, and they advance the principle of control by host separation but yield nothing definite on the practical application of control measures suited to American conditions. During the period from 1917 to 1921 the United States Department of Agriculture, in cooperation with the New England States, New York, Wisconsin, and Minnesota, conducted extensive experiments to develop methods of practical control of the disease under forest conditions.

These experiments have fully demonstrated that under average forest conditions in the northeastern United States, white pine can

¹ The serial numbers (italic) in parentheses refer to "Literature cited" at the end of this bulletin.

be effectively protected (10). Control is accomplished by uprooting all wild and cultivated currant and gooseberry plants (*Ribes*) within a distance of 600 to 900 feet of the trees to be protected. The destruction of wild currant and gooseberry bushes can be accomplished at a cost sufficiently low to make it practicable and profitable to safeguard the valuable white-pine crop of the Northeastern States. In the five years from 1918 to 1922 the cost of removing 19,224,118 wild currant and gooseberry bushes from 1,504,945 acres of forest and pasture land averaged 31.8 cents per acre. Any white-pine stand protected in this manner is safe from further rust infection for at least 5 to 10 years, and in many cases permanently, depending on whether or not local conditions are favorable or unfavorable to the growth of wild currant and gooseberry bushes. Several years of careful study are required to develop and perfect the cheapest and simplest methods of control, since many phases of this work are still in the experimental stage. Meanwhile, the control measures that have been developed should be generally applied at once to prevent further losses from this disease.

The writer, a forester, observed the blister-rust situation in several European countries in 1919 and 1920 and takes this opportunity to acquaint others with his observations, which should be of especial interest to timberland owners on account of the rapid spread of the disease in the Northeastern States and its occurrence in British Columbia and Washington. Unless otherwise specified, the statements are based on the writer's observations. It would have been quite impossible to conduct the work without the assistance and advice of scientists, departments of agriculture, and forest officials in the countries visited. The writer wishes to express his sincere appreciation to those who freely gave their time and efforts, which contributed so largely to the progress of this work.

SCOPE OF THE INVESTIGATIONS.

The primary purpose of this work was to gather information regarding European methods of dealing with the white-pine blister rust which would assist in the control campaign in America. To accomplish this purpose, plantations of infected white pine were studied, foresters and pathologists interviewed, and data compiled as to the actual and financial loss caused by the disease. This work was supplemented by visiting the nurseries to observe their sanitary conditions, in order that a first-hand opinion might be formed as to the justification of the rigid quarantine regulations adopted by the United States against imported nursery stock. In addition, all available historical and biological data concerning the fungus were collected in Norway, Sweden, Denmark, Great Britain, France, and Belgium. Typical specimens of ornamental white pine were seen very frequently in European parks and arboretums (Pl. I.). Even under the most favorable conditions they become prey for the blister rust.

As the writer was in Sweden during the fall of 1919 and winter of 1919-20, work was begun in that country and extended to cover Norway and Denmark. By the middle of July the field was shifted to the British Isles, then to France and Belgium, which were completed on November 1, 1920. Miscellaneous notes were also gathered

by correspondence from other European countries, including Germany, Switzerland, Holland, and Russia, although these countries were not actually visited.

HISTORICAL REVIEW.

Both the *Peridermium* and *Cronartium* forms of *Cronartium ribicola* have been known in Europe for 65 years. Dietrich first used the name about 1856 in a collection of dried plants entitled "Plantarum Florae Balticae Cryptogamarum" (11, p. 287), and European writers generally attribute the name to him. Five years later, in 1861, W. Saellen discovered the fungus on white pine near Helsingfors, Finland. The form on *Ribes*, as far as is known, was not found in that country until 1897 (28, p. 447-449). Rostrup, in 1865, found the disease in Denmark on black currants, while Kornicke first found it in East Prussia in 1865 (27, p. 281). It was unknown in the rest of Germany until Fischer de Waldheim found it on *Ribes aureum* at Stralsund in 1871.² The following year Magnus found it on the same species at Kiel (29).

The disease was reported on one or both hosts from western Siberia in 1879,³ Sweden in 1880 (14), Norway in 1885 (7, p. 70), Holland in 1885 (32, p. 239), France in 1889,⁴ and during the following decades from the British Isles in 1892 (33), Belgium in 1894 (31), and Switzerland in 1895 (15). The date 1887 is perhaps the most significant in blister-rust history, for in that year Klebahn separated the old composite species *Peridermium pini* Willd. into three species, namely, *Peridermium pini ribicola* Kleb., *Peridermium cornui* Rostrup and Klebahn, and *Peridermium strobis* Kleb. (23).

In 1888 Klebahn determined by inoculation experiments the relationship between the *Peridermium* form on *Pinus strobus* and the *Cronartium* form on *Ribes*. The same year, in company with O. Nordstedt at Grimstorp, Westgotland, Sweden, this belief was verified when they found white pine and black currants growing close together and both badly diseased (22).

Following the determination of the host plants the fungus has been repeatedly found and reported from several European countries, attracting the attention of both mycologists and foresters. Its distribution covers nearly the whole of western Europe and the British Isles and, according to statements by members of the Norwegian forest service, extends to 63½° north latitude on the Norwegian coast. The date of the introduction of the blister rust into America is not known, but circumstantial evidence indicates that it was first introduced from Europe about 1898.

SUSCEPTIBILITY OF BLISTER-RUST HOSTS.

FIVE-NEEDLE PINES.

The current European opinion is that the fungus originated on *Pinus cembra* in Siberia, migrated to Europe, and became far more virulent on the exotic five-leaved pines than on its supposed original host. Contrary to the writer's expectations, he found no *Pinus*

² Rabenhorst, L. *Fungi europaei exsiccati*, No. 1595.

³ Thumen, Felix von. *Mycotheca universalis*, No. 2049.

⁴ Specimen. Natural History Museum, Paris.

cembra infected in the countries visited, although a single instance of its occurrence on this species is reported from Switzerland (37). Besides occurring on *Pinus cembra* and *P. strobus*, it has been found (and seen by the writer, except as otherwise noted) in Europe on other species as follows: *P. ayacahuite* Ehrenb. (British Isles and Belgium), *P. excelsa* (Denmark, 36, p. 312), *P. flexilis* (Belgium, France, Germany (42), Norway, Sweden), *P. koraiensis* (Sweden), *P. lambertiana* (Belgium, British Isles, France, Germany (42)),⁵ *P. monticola* (Belgium, British Isles, Germany (42)), *P. pentaphylla* (British Isles),⁶ and *P. peuce* (Belgium,⁷ Germany (42)).

Inoculation experiments successfully conducted by many European investigators show that all five-leaved pines and *Ribes* tested are susceptible to the fungus, though varying greatly in their degree of susceptibility. The experiments also prove the independence of the two forms *Peridermium pini* and *P. strobi*. It is worthy of mention at this point that the earliest known *Cronartium* on *Ribes*, though not *C. ribicola*, was collected by Jacquemont (43), the French explorer, in India in 1830 and determined by Leveille as *Cronartium asclepiadeum*.⁸ This is particularly significant, since in 1914 a bark-inhabiting *Peridermium* was found on the Himalayan white pine (*Pinus excelsa*) and sent to the Mycological Bureau at Pusa, India. Dr. E. J. Butler, of the Bureau of Mycology at Kew, England, kindly forwarded a specimen of the *Peridermium* to the writer, who sent it to Dr. R. H. Colley, of the Office of Forest Pathology, for determination. He found it to be distinctly different from *Cronartium ribicola*.

CURRENTS AND GOOSEBERRIES.

Herbariums in the botanical museums were carefully scanned for *Ribes* species serving as hosts for *Cronartium ribicola* and for the localities and dates of occurrence. A total of 29 species was recorded, covering all the western European countries. Of the common *Ribes*, the most readily infected is *nigrum* (41), while *grossularia* and *rubrum* are less susceptible. The writer found the first-mentioned species, but not the last-mentioned, infected in Europe. In the Vil-morin Arboretum at Nogent sur Vernisson, Loiret, France, 35 species were examined, and only two were found infected, namely, *Ribes caucasicum* and *Ribes propinquum*, both of which were badly diseased. European foresters regard *Ribes nigrum* as the most dangerous species and consider other European *Ribes* as of little consequence as agents for harboring the white-pine blister rust.

CURRENTS AND GOOSEBERRIES KNOWN TO BE SUSCEPTIBLE.

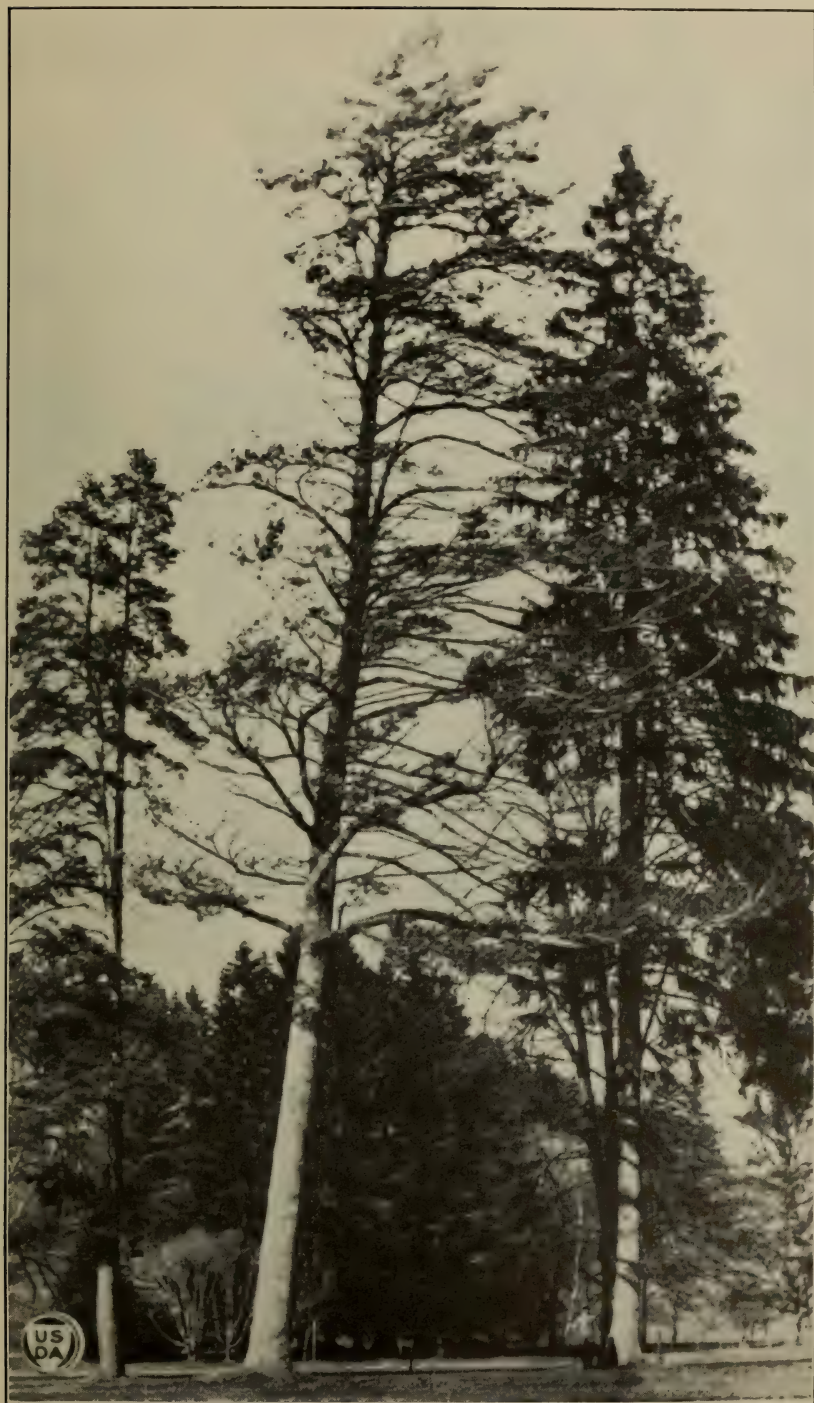
The list of varieties shown in Table 1 includes all infected species of *Ribes* seen by the writer in herbariums and elsewhere in Europe, as well as those observed by a correspondent, Prof. O. Juel, in 1920, in the Botanical Gardens at Upsala, Sweden; but undoubtedly other host species exist in other European collections.

⁵ Correspondence with Professor Von Tubeuf.

⁶ Reported by the Forestry Commission for Scotland.

⁷ Reported as having occurred at Groenendaal, Belgium.

⁸ Specimen in Cryptogamic Herbarium, Botanical Museum, Paris.



A CENTURY-OLD WHITE PINE IN BELGIUM.

This magnificent specimen in the Domaine of St. Ode, Luxembourg, is one of our finest American trees on foreign soil. Photographed by Prof. Charles Bommer, Brussels, Belgium.



A GROUP OF 70-YEAR-OLD WHITE PINES IN BELGIUM.

The largest tree in this group, at the farm St. Michel, near St. Hubert in the western Ardennes, in 1909 measured 110 feet in height, with a diameter of 33 inches at breast height. This tree would cut 1,400 board feet, valued in Europe at approximately \$40 per thousand on the stump. Photographed by Prof. Charles Bommer, Brussels, Belgium.

TABLE 1.—List of species of *Ribes* infected with blister rust as seen by the writer in certain herbariums and elsewhere in Europe and by Prof. O. Juel in the Botanical Gardens at Upsala, Sweden.

[Names recorded from the specimen labels are shown in **boldface** type. The synonymy has been furnished by Dr. Frederick V. Coville, and the synonyms are here printed in SMALL CAPITALS. Doctor Coville believes that the gooseberries are more satisfactorily regarded as belonging to *Grossularia*, a genus distinct from *Ribes*, which comprises the currants. The species are so treated in the revision of the family *Grossulariaceae* in the North American Flora (9). American species or varieties are designated by an asterisk (*). *Explanation of symbols*.—Bru=Botanical Museum, Brussels, Belgium; Chr=Botanical Museum, Christiania, Norway; Cop=Botanical Museum, Copenhagen, Denmark; Lon=British Museum, London, England; Sto=Royal Museum at Stockholm, Sweden (contains the herbariums of Rehm and Sydow, as well as those of Swedish collectors; Upsala=Botanical Gardens, Upsala, Sweden; Vil=Vilmorin Arboretum, Nogent sur Vernisson, France.)

Name of species.	Where seen.	Remarks.
Seen by the writer:		
albidum* L.....	Lon.....	This presumably is <i>Ribes albidum</i> Paxton, which is an albino form of <i>R. glutinosum</i> Benth.
alpinum L.....	Chr, Lon, Sto.....	See floridum .
AMERICANUM* Mill.....		According to Janczewski (22) this is a horticultural variety of <i>R. nigrum</i> L.
apifolium	Lon, Sto.....	According to Janczewski this is a variety of <i>R. petraeum</i> Wulf.
atropurpureum Mey.....	do.....	This is probably <i>R. odoratum</i> Wendl., the common very sweet-scented golden currant of gardens which often passes under the name <i>R. aureum</i> Pursh, a related species seldom cultivated and with little odor. See also ginkae-folium and tenuiflorum .
aureum* Pursh.....	Chr, Cop, Lon, Sto.....	Listed as <i>holosericeum</i> No. 7432 in Vilmorin's catalogue. This is probably <i>R. holosericeum</i> Otto and Dietr., a hybrid of <i>R. petraeum</i> and <i>R. rubrum</i> .
caucasicum	Vil.....	See gracile .
cynosbati* L.....	Lon.....	See saxatile .
DIACANTHA Pall.....		The name <i>R. floridum</i> L'Her., published in 1785, is a synonym of the much older <i>R. americanum</i> Mill., published in 1768.
floridum* L'Her.....	Lon.....	The name <i>R. fontanesii</i> Colla is a synonym of <i>R. odoratum</i> Wendl.
fontanesii* Colla.....	Lon, Sto.....	This is presumably a form of <i>R. aureum</i> catalogued for many years by Spaeth, a Berlin nurseryman, under the name <i>R. aureum gink-gifolium</i> .
ginkae-folium*	do.....	See albidum .
GLUTINOSUM* Benth.....		This is a well-known hybrid between <i>R. odoratum</i> and <i>R. sanguineum</i> .
gordonianum* Lem.....	Lon, Sto.....	Michaux's <i>R. gracile</i> is a smooth-fruited form of <i>R. cynosbati</i> L., but the plant that usually passes under the name <i>R. gracile</i> is <i>R. missouriense</i> Nutt., the Missouri gooseberry.
gracile* Michx.....	Sto.....	According to Janczewski this is a variety of <i>R. punctatum</i> Ruiz. and Pav.
grossularia L.....	Bru, Cop, Lon, Sto.....	See caucasicum .
heterophyllum Phil.....	Lon, Sto.....	According to Dippel <i>R. intermedium</i> is a hybrid between <i>R. americanum</i> and <i>R. nigrum</i> .
HOLOSERICUM Otto and Dietr.....		Inoculated by Prof. W. Somerville, of Oxford.
intermedium Tausch.....	Lon, Sto.....	
longiracemosa Wilson.....		
macrobotrys Ruiz and Pav.....	Lon, Sto.....	
menziesii* Pursh.....	do.....	This is a well-known gooseberry of southern Oregon and northern California, but the name has often been misapplied to other Pacific coast species. See subvestitum .
missouriense* Nutt.....	do.....	
nigrum L.....	Bru, Chr, Cop, Lon, Sto.....	See also apifolium .
niveum* Lindl.....	Lon, Sto.....	See aureum and fontanesii .
ODGRATUM* Wendl.....		
orientale Desf.....	Lon, Sto.....	
oxyacanthoides* L.....	do.....	This should be parvifolium Phil.
parvifolia* Phil.....	do.....	See also atropurpureum .
petraeum Wulf.....	Cop, Sto.....	According to Janczewski this is <i>R. warszewiczii</i> Jancz.
propinquum Turcz.....	Vil.....	See heterophyllum .
PUNCTATUM Ruiz and Pav.....		

TABLE 1.—List of species of *Ribes* infected with blister rust, etc.—Continued.

Name of species.	Where seen.	Remarks.
Seen by the writer—Con.		
<i>racemosa</i> Wilson.....	Lon, Sto.....	Inoculated by Prof. W. Somerville, of Oxford.
<i>rotundifolium</i> * Michx.		
<i>rubrum</i> L.....	Bru, Cop, Sto.....	
<i>sanguineum</i> * Pursh.	Lon, Sto.....	
<i>saxatile</i> Pall.....	do.....	This is <i>R. diacantha</i> Pall.
<i>setosum</i> * Lindl.....	do.....	
<i>subvestitum</i> *.....	do.....	The original <i>R. subvestitum</i> published by Hooker and Arnott is a synonym of <i>R. menziesii</i> Pursh., but other Pacific coast species of gooseberry have sometimes passed under the name of <i>R. subvestitum</i> .
<i>tenuiflorum</i> Lindl.....	Lon.....	This is a synonym of <i>R. aureum</i> Pursh. The name has sometimes been misapplied to <i>R. gracillimum</i> Coville and Britton.
WARSZEWICZII Jancz.....		See propinquum .
Seen by Prof. O. Juel:		
<i>americanum</i> * Mill.....	Upsala.....	
<i>aureum</i> * Pursh.....	do.....	
<i>biebersteinii</i> Berl.....	do.....	This is regarded by Janczewski as a variety of <i>R. petraeum</i> Wulf.
<i>divaricatum</i> * Dougl.....	do.....	
<i>divaricatum</i> var. <i>glabrifolium</i> .	do.....	This is probably intended for <i>divaricatum</i> var. <i>glabriflorum</i> Koehne, a smooth-flowered form of <i>R. divaricatum</i> Dougl., a common northwest-coast gooseberry.
<i>gordonianum</i> * Lem.....	do.....	
INERME Rydberg.....	do.....	See oxyacanthoides nevadensis .
<i>multiflorum</i> Kit.....	do.....	
<i>nigrum</i> L.....	do.....	
<i>orientale</i> Desf.....	do.....	
oxyacanthoides nevadensis *.....	do.....	This is <i>R. inermis</i> Rydberg, the wine gooseberry.
PETRAEUM Wulf.....	do.....	See biebersteinii .
<i>pinetorum</i> * Greene.....	do.....	
<i>pubescens</i> Sw.....	do.....	This is doubtless <i>R. rubrum pubescens</i> Swartz.
<i>rubrum</i> L.....	do.....	See also <i>pubescens</i> .
<i>sanguineum</i> * Pursh.....	do.....	
<i>sylvestre</i> Mert. and Koch.....	do.....	This is a synonym of <i>R. vulgare</i> Lam.
VULGARE Lam.....	do.....	See sylvestre .

RELATION OF WHITE PINES TO EUROPEAN FORESTRY.

European forest conditions form a striking contrast to those in America. In Europe conservative methods of management and utilization have been in practice for centuries, whereas in America we are considering only the ways and means of applying such methods. Labor costs, though now abnormally high in Europe, as elsewhere, have usually been very low, a factor which has contributed largely to the success of forest practice abroad. With the development of forestry as a science, exotic tree species have been sought for study and experimental planting. There has been a continual search for species which would become readily naturalized and establish themselves under different conditions of planting and site. Trees from the New World were eagerly sought after, both for ornamental and forest planting. Many of the newcomers soon found a permanent place in the list of desirable species for use by the arboriculturist and the forester, foremost among which was *Pinus strobus*.

In Europe the eastern white pine of North America (*Pinus strobus*) is invariably called "Weymouth pine." According to Belon (8) this tree was growing in the royal nurseries at Fontainebleau, France, in 1553. If that is true, it is the earliest record of its appearance in Europe. It was not until after its introduc-

tion into England in 1705 and later into other European countries that the tree became prominent abroad. From the beginning its distinct and ornamental beauty interested foreigners (Pls. I and II). Gold and silver medals were offered for plantations of Weymouth pine in England by the Society for the Encouragement of Arts in 1765 (1). This tree is now well known abroad and is one of the most widely distributed of introduced American species. Unfortunately in several countries *Cronartium ribicola* has taken such heavy toll that some foresters are wary of planting it, while others have absolutely discontinued its cultivation.

White pine although widely distributed is not the commercially important forest tree in Europe that it is in America, for it is not a native species. The total area which it occupies is negligible in comparison with the forested areas of European countries. The ease with which the wood can be worked and its varied uses for joinery, pattern making, matches, and in shipbuilding for masts, yards, and deals brought imported white pine into much demand abroad. According to Laslatt, timber inspector of the British navy, when ships were built of wood "white pine served well for masts and bowsprits," but he says it was not strong enough for light spars subject to great and sudden strain. For such requirements it was surpassed in strength and durability by Oregon fir (25, p. 356-366).

To-day in Europe it is difficult to obtain white pine free from knots and sapwood. In England the value of the best quality is advanced to 6s. (\$1.50) per cubic foot. During the war the timber controller fixed the maximum price at 9s. 8d. per cubic foot, or approximately \$389.75 per thousand board feet (20).

Standing white pine has brought equally high prices. A 70-year-old plantation cut in Surrey during the war yielded a clear profit of \$340 per acre. In the Vosges region of France 60-year-old plantations on optimum sites have yielded 68,590 board feet per acre, with a stumpage value of \$44.53 per thousand board feet. Other plantations near Epinal in the French Vosges at the age of 55 years have produced a volume of 42,900 board feet per acre (fig. 1). In Germany, pure stands 104 years old yielded 81,538 board feet per acre, while stands 68 years of age produced 61,560 board feet per acre (44).

In volume production and rapidity of growth white pine ranks high. In the Vosges of France at 60 years it has shown a mean annual growth of 190 cubic feet per acre, a figure which has been equaled in Belgium. At Oxford, England, at 12 years the yield was 181 cubic feet per acre. It was outclassed in mean annual volume production by Douglas fir (*Pseudotsuga taxifolia*) from Vancouver, western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and Sitka spruce (*Picea sitchensis*). The diameter growth of white pine, however, was good. Trees 12 years old with 3.2 inches average diameter at breast height were exceeded only by Vancouver Douglas fir with an average diameter of 3.4 inches (38).

A recent Belgian publication (16, p. 14) states that the only merit of white pine from its viewpoint is its large volume production and that its reputation as a tree with a future in Belgium has been overestimated. Bommer and Visart, on the other hand, credited white pine with being the one pine which up to the present has been cultivated successfully on the high plateau of the Ardennes (6). In

1911 an English writer said that the blister rust caused much damage to young trees, and it was not valuable enough to plant as a forest tree except on a small scale (17, p. 173). Similarly, Baltz in Ger-



FIG. 1.—A 55-year-old white-pine plantation in the French Vosges, yielding 42,900 board feet per acre. Note the clean straight trunks of the trees. Such a crop is profitable, and there are many stands similar to this in the white-pine regions of northeastern America.

many suggested caution in planting white pine on a large scale (4). Henceforth, owing to the destructive power of the blister rust, white pine will be planted commercially less and less in Europe.

Other members of the American five-leaved pine group have been introduced into Europe, but only for ornamental and experimental planting. The sugar pine (*Pinus lambertiana*), the most valuable commercial timber tree on the Pacific coast, was introduced into England by Douglas in 1827 and later into other European countries. The western white pine (*Pinus monticola*), since its introduction into England by Douglas shortly after 1831, has been planted here and there in the British Isles and European countries as an ornamental tree (12). The limber pine (*Pinus flexilis*), a native of the Rocky Mountain region, has been planted scatteringly in Europe for ornamental and experimental purposes. Specimens are to be found in the British Isles, Belgium, France (fig. 2), Norway, Sweden, and Germany, but there are no extensive plantations. Others more rarely found are *P. albicaulis*, *P. balfouriana*, *P. monophylla*, and the Mexican white pine (*P. ayacahuite*). These trees have no commercial future in Europe, but are valued and sought continually for park and arboretum planting by tree enthusiasts. The Himalayan white pine (*Pinus excelsa*) and the Balkan white pine (*Pinus peuce*), both five-needle species, indicate favorable growth possibilities combined with more or less resistance to *Cronartium ribicola* and will undoubtedly become more popular abroad for forest planting.

IMPORTANCE OF CURRANTS AND GOOSEBERRIES.

Currants and gooseberries are universally grown in the cultivated areas of western Europe and are far more extensively used abroad than in this country, fulfilling many demands, such as making jellies, jams, pastries, and wine. Black currants (*Ribes nigrum*) generally predominate, although red currants, gooseberries, and ornamental species are common. Wild *Ribes* are usually limited to five species, *R. rubrum*, *R. nigrum*, *R. grossularia*, *R. alpinum*, and *R. petraeum*. In several countries only the first four occur, but not abundantly. This scarcity, however, is more than compensated for by the presence of the cultivated bushes, which are everywhere valued as a small fruit. Some 35 varieties of *Ribes nigrum* are described in the fruit catalogue of the Royal Horticultural Society.

Currant bushes frequently form the principal ornament in some of the gardens of European country cottages, and it is often customary to train the bushes against the walls of the house. There are nearly 200 varieties of gooseberries, including yellow, green, white, and red, which are made into jams and jellies. The wine made from the best yellow gooseberries has a flavor resembling champagne. Single gooseberries have weighed as much as $1\frac{7}{12}$ ounces (troy weight). At Duffield, near Derby, England, a bush 46 years old had a circular spread of 12 yards, and bushes at Chesterfield, England, trained against a wall, measured 50 feet from one extremity to the other (3).

The northernmost point at which *Ribes rubrum* grows is near Hammerfest, Norway, some 300 miles above the Arctic Circle. Other species, as *R. nigrum*, *R. grossularia*, and *R. alpinum*, are also found growing above the Arctic Circle.⁹ *Ribes* species are essentially adapted to a cold moist region, and in Europe they usually do not

⁹ Notes from the Botanical Museum, Christiania, Norway.

thrive in a warm dry climate. This distribution is well illustrated in France, where both wild and cultivated bushes are confined to the northern part of the country and the cooler regions in the vicinity of the mountains to the east and south. They do not occur in central France (24), where the climate is warm and dry. The *Ribes*



FIG. 2.—Limber pine (*Pinus flexilis*) of western North America, growing in the National Arboretum at Nogent sur Vernisson, Loiret, France. This tree, although thriving under its new surroundings, was attacked by the blister rust on two limbs, one located 2 feet and the other 4 feet above the ground.

of India, eight species in all, do not grow in the hot and dry areas, but in the Himalayan region (19) at altitudes between 7,000 and 13,000 feet. The *Ribes* distribution of the North Temperate Zone coincides closely with that of the five-leaved pines, affording optimum conditions for the development of the blister rust.

The universal cultivation of black currants in western Europe, although red currants and gooseberries are also grown, is the primary cause of the widespread distribution and seriousness of the disease in these countries. White pine is of less importance to the happiness and welfare of the average European than are these popular *Ribes* fruits which have been so carefully cultivated for centuries. Foresters have found a substitute for white pine in other fast-growing conifers, but no fruit to replace the currant and gooseberry. On account of the blister rust white pine can not be cultivated further at a profit, and the forester must respond to the popular demand to give up the exotic white pine rather than require the farmer and gardener to forego a profitable and widely grown crop. An excellent example of the damage done to white pine by the blister rust when black currants are near by to spread the fungus is shown in Figure 3.

DAMAGE TO EASTERN WHITE PINE IN EUROPE.

The earliest observation of damage to *Pinus strobus* by *Cronartium ribicola* is recorded by Hisinger in Finland, 1869 (18), who states that 30-year-old trees attacked on both the stems and limbs were being killed by the rust. Prior to 1870 the fungus had been reported in Denmark and later became so widely spread that in several places the cultivation of *Pinus strobus* was abandoned (27, p. 281). During succeeding years the fungus was discovered in other European countries, causing damage and killing trees. Information upon the subject is fragmentary, as no accurate records or data have been kept. Only meager notes were made concerning the occurrence of the fungus and the killing of the trees. It is quite natural that the European foresters should not regard the disease in the same light as American foresters, since, as previously stated, white pine is an introduced species of secondary economic importance. The fact that the tree is susceptible to the rust is sufficient in most cases to create prejudice against its further planting.

SWEDEN.

The general opinion expressed by the members of the forestry profession and of the Swedish experiment station is that the white pine is not adapted for planting in their country. The blister-rust attacks have been a potent factor in developing this attitude, for the pine has become infected wherever planted. A forester in northern Sweden states: "*Pinus strobus* is not a tree for my forest. It is quite impossible for me to raise it, for *Cronartium ribicola* [white-pine blister rust] causes great loss, particularly to young trees." Similar statements have been received from other parts of the country.

NORWAY.

Norwegian foresters have held white pine in very high regard because of its rapid growth and yield capacity, as well as its ability to regenerate naturally. To-day their attitude is very unfavorable, because of the destruction caused by the rust in their plantations. The Norwegian forest service has not used the species in its experimental plantations for several years and henceforth will not cultivate it. The few plantations made in the past have been thinned out by the disease until only a few white pines remain in the whole country.

One small 28-year-old experimental plantation at Jelsa had 100 per cent of the trees attacked by the blister rust and 6 per cent already destroyed. None of the remaining trees will make merchantable timber.



FIG. 3.—A white-pine tree growing near black currants at Bagley Wood, near Oxford, England. This tree illustrates the typical appearance of white pines in a 12-year-old plantation in which 95 per cent of the trees are attacked by blister rust. Each limb shown here, as well as the trunk, is diseased.

DENMARK.

The white-pine blister rust has been known on the island of Bornholm, Denmark, since 1890, when Rostrup collected the first infected twig at Almindingen.¹⁰ Since that date the disease has become preva-

¹⁰ Pathological collection, Royal Agricultural College, Copenhagen.

lent in plantations, doing such serious damage that the foresters have stopped planting the species. In one pine plantation in the Almindingen forest 91 per cent of the trees 20 to 30 years old have been attacked by the rust, and it is estimated that 75 per cent will be a total loss in 10 years, disregarding the probable damage from further infection. No merchantable product will be obtained, and the only revenue to be derived is from the sale of wood cut for fuel from the dead and dying trees, which barely covers the cost of cutting and is insufficient to pay for the original cost and maintenance of the plantation. The piling of the tops of white-pine trees felled because they were dead or dying from the blister rust and salvaged for fuel is illustrated in Figure 4.

In another pure stand of 24-year-old white pine, covering 16 acres, 90 per cent of the trees were attacked, and it is estimated that in 10 years 82 per cent of the trees will be dead. Out of 1,060 trees 20 to 30 years old examined in the Almindingen forest 90 per cent were diseased, and it is estimated that 78 per cent will be dead in 10 years. These figures represent the condi-

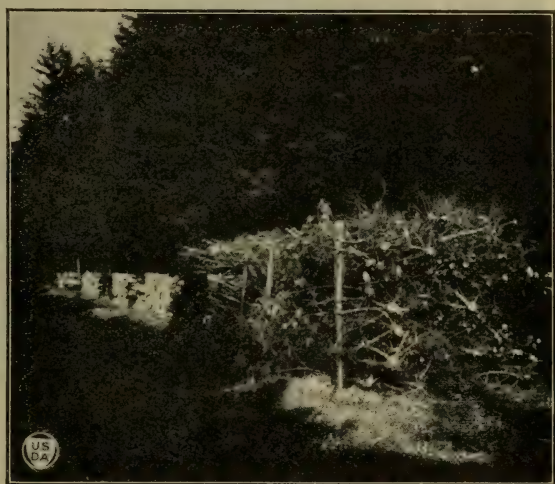


FIG. 4.—Salvaging the dead and dying white pines following a blister-rust attack on the island of Bornholm, Denmark. The tops and limbs, as well as the stems, are piled into cubic meters and sold for fuel.

tions in the entire stand. The actual loss can not be determined, because many diseased trees have already been cut. The typical condition of the white pines on the island of Bornholm, Denmark, where the destruction by the blister rust has been complete, is shown in Figures 5 and 6. The Danish foresters have a peculiarly descriptive term which they apply to the white pine. Their name for this tree is "Weymouthsfyr," but they commonly speak of it as "vemodsfyr" or the "melancholy pine," and this aptly expresses its appearance after it is attacked by the blister rust.

In the Corselitz forest, located in the northeastern portion of the island of Falster, the blister rust has so badly damaged the white-pine plantations that the cultivation of the species has been discontinued. Oak, a more profitable crop for this forest, is being used in some cases to replace the white pine (Pl. III).

BRITISH ISLES.

The damage to white pines in England has been serious. A study of a 12-year-old plantation at Bagley Wood, Oxford, revealed so much injury inflicted by the blister rust during the early life of the stand that it will be impossible to obtain timber of commercial value from the plantation. The occurrence of the disease here is interest-



FIG. 5.—Interior of a 24-year-old white-pine plantation at Almindingen, island of Bornholm, Denmark, showing the destruction caused by the blister rust, which has killed 32 per cent of the trees. The rest are dying from the disease.

ing, in that it showed a decrease in the amount of infection with the increase of the distance from *Ribes* to pine. Within 200 feet of the *Ribes* bushes (18 black currants, 3 red currants, and 7 gooseberries) 95 per cent of the trees were diseased (fig. 7). Farther away, at 570



FIG. 6.—Exterior view of the plantation shown in Figure 5. Even the trees showing the best height growth are badly diseased.

feet, it had decreased to 10 per cent, and at 1,096 feet no disease whatever was found.

In the Windsor Park forest at Surrey, 67 per cent of the white pines, approximately 20 years old, were attacked by the blister rust. Of these, 17 per cent had been killed and 25 per cent were in a dying condition. This plantation was made in mixture with *Pinus sylvestris* and other conifers, and the loss due to the disease is perhaps less than it would have been if the plantation had been purely *Pinus strobus*.

In 1896 *Pinus monticola* was observed to be fatally diseased in Scotland (26). A few years later some fine old trees were felled because of the damage inflicted by the rust. Hereafter in the British Isles white pine must be planted with caution and never in the vicinity of black currants, as has been the custom in the past. It will be



FIG. 7.—A 12-year-old white-pine plantation at Bagley Wood, near Oxford, England, in which 95 per cent of the trees are attacked by the blister rust and 84 per cent are in a dead or dying condition, within 100 feet of where 18 black-currant bushes were growing.

well also to plant white pine in mixture with other conifers, rather than pure, in order to provide all possible protection from the screening afforded by other trees.

FRANCE.

French foresters minimize the menace of the blister rust to their white-pine plantations and maintain an optimistic viewpoint, because the old trees on a casual inspection do not appear to be seriously injured. This is not true for the young age classes. As far as could be learned, the disease has been known on pine in that country only since 1890 (34, p. 342). It is present and destroying natural reproduction in the Vosges district, where the writer found clumps in which 49 per cent of the regeneration was diseased (fig. 8). After the felling of the mature stands the damage will be more striking in the young growth. If new plantations are made the disease is certain to attack them severely before they are 15 years old; that is, assuming that the

Ribes bushes are not removed as an act of protection, which seems quite unlikely. Plate IV shows a 50-year-old tree in the communal forest near Épinal, France, killed as a result of severe crown infection by blister rust. Inspection of wind-thrown trees in another section of the same forest revealed many infections and conclusively proved that no tree is too large to be attacked and killed by this disease.

BELGIUM.

The damage in Belgium has been large, but few detailed data are available as to the actual extent of destruction. At one time the future of white pine in that country was regarded as particularly bright because of the success with which it had been grown in the Ardennes. In fact, it is the only pine which has been successfully



FIG. 8.—Natural regeneration of white-pine trees 3 to 15 years old which have grown in an opening made in the overwood of pine and spruce. In a sample plat 25 feet square 49 per cent of the trees were infected with blister rust. Diseased twigs are marked with pieces of paper, and the tree with the cap on the trunk is dying.

cultivated in the high plateaus of that region. This opinion has been altered, owing to the damage done by blister rust. In an 18-year-old plantation studied by the writer, 50 per cent of the trees have been killed and 53 per cent of those remaining were diseased. The forester in charge of another severely infected plantation said he considered it best to destroy the entire lot and replant with another species, since the white pine could not be grown to commercial size. In the opinion of the Belgian forest service it can not afford to plant the tree extensively because of its susceptibility to attack and damage by *Cronartium ribicola*.

The figures in Table 2 accompanying were obtained from studies made in typical infected white-pine stands for the purpose of showing the average diseased condition of the entire plantation. They illustrate representative conditions in the countries visited. In most



REMNANT OF A 20-YEAR-OLD WHITE-PINE PLANTATION, CORSELITZE,
DENMARK.

Each of the 200 remaining trees is diseased with blister rust on the stem or limbs or both. The most severely infected trees have been felled. Those left are now used as a cover crop for the pedunculate oak, *Quercus pedunculata* Ehrh. As soon as the oak becomes well established all the white pines will be cut.



WHITE PINES IN A COMMUNAL FOREST NEAR EPINAL, FRANCE.

The 50-year-old tree bearing the cap has been killed by the white-pine blister rust, while other trees in the opening in the background have serious crown infections.

cases the site chosen for the plantation was favorable to the growth of white pines. The Windsor Park woods, England, were too sandy for its best development, and the location at Almindingen, island of Bornholm, Denmark, was too wet.

TABLE 2.—Summary of typical European conditions with respect to the infection of pine trees with blister rust.

Country and locality.	Area studied.	White-pine (<i>Pinus strobus</i>) trees examined.								Black currant (<i>Ribes nigrum</i>).	
		Average height.	Number.	Attacked by rust.		Killed by rust.		Dying from rust.		Distance from pines.	Number.
				Number.	Per cent.	Number.	Per cent.	Number.	Per cent.		
England:	<i>Acres.</i>	<i>Feet.</i>									
Oxford.....	2	20	111	105	95½	21	19	73	65.7	190	18
Windsor Park.....	25	25	394	67	17	17	4.3	17	4.3	1,760 to 4,600	100
Norway:											
Jelsa.....	1½	35	159	159	100	107	67	52	32	150	10
Fjosanger.....	¼	25	20	100	100	5	25	15	75	500	12
Sweden:											
Atvidaberg.....	1	30	30	25	83			3	10	3,500	150
Denmark:											
Almindingen.....	{ 15	20	517	404	90	168	32	184	33	820	15
	{ 16	35	543	493	91	94	17	245	45	3,000	50
France:											
Lesbarres.....	5	15	31	5	16			4	13	1,600	35
La Mouche, Epinal {	4	10	63	31	49	7	14			2,500	30
	6	12	75	27	36			7	1	2,500	30
St. Oger.....	2	7	135	26	19	6	4			3,300	10
Deyvillers.....	2	18	89	42	47	7	7			870	10
Belgium:											
Gedinne.....	{ ¼	25	41	27	65			19	46	3,160	3
	{ 4½	20	62	100	100	6	9	51	80	524	5
	{ 2	12	37	21	57					430	15
Total or average.	86½	21	2,307	1,574	68	438	19	670	29	1,653 to 1,843	493

The European situation may be briefly stated as follows: The white-pine plantations in some countries are disappearing as a result of the damage by the rust, and foresters quite generally express the opinion that the loss resulting from the disease is too large to permit raising the species at a profit. The white-pine plantations are being replaced by other foreign conifers of good growth rather than protecting them by destroying the *Ribes*.

CONTROL MEASURES RECOMMENDED IN EUROPE.

When foresters and pathologists recognized the damage being done to the white pine by the rust they began to consider means of combating it to save their plantations and ornamental trees from destruction. Although in Europe the white pine is an exotic tree, *Cronartium ribicola* is believed to be a native fungus indigenous to Siberia. The exact reverse of this condition applies to the United States, where the fungus is rapidly becoming too well naturalized in its new environment.

For at least 30 years European writers have recommended methods of control, though rather indefinitely, and have even proposed curative treatment for infected trees. The writer found that control measures were rarely put to a practical test. The seriousness of the disease is fully realized, and its life history is well known, but

it took some years for it to become sufficiently well established to attract much attention. The most effective control method, consisting of *Ribes* extermination in the neighborhood of white-pine plantations, has seldom been practiced. Popular opinion favors saving the black currants rather than the exotic white pine, because the people have a greater appreciation of their native currants than of a foreign tree.

SWEDEN.

Among the earliest recommendations for control are those made by Prof. Jakob Eriksson in Sweden in 1890 (13). He informed the writer that the control of the fungus by the removal of the *Ribes* had not been undertaken in Sweden. For some years white pine had been grown in nurseries at Djurgarden, Stockholm, but its cultivation was stopped in 1897 because of the increasing loss from *Cronartium ribicola*. At least 50 per cent of the seedlings between the ages of 3 and 5 years became diseased. All such infected stock was pulled out and burned, and Professor Eriksson gave orders that no white pine from the nursery was to be shipped to other parts of the country.

Black currants and gooseberries were grown near the white-pine beds, the former species showing severe infection annually. The significant feature is that the cultivation of white pine ceased, while that of *Ribes* continued. A few old trees planted in the park at Djurgarden early in the nineteenth century became infected in the crown and on the side limbs. These trees were carefully treated by removing the diseased limbs, so that to-day they still survive, although somewhat lacking in natural symmetry because of the pruning away of the infected branches.

NORWAY.

A Norwegian writer, Schøyen, in 1895 recommended growing the *Ribes* and pine apart from each other (39, p. 56). This advice was followed in 1904 by Director Saxelund, of the Norwegian forest service, who ordered that no more *Pinus strobus* should be planted in the Government nurseries at Sandnes.¹¹

DENMARK.

Rostrup, in Denmark, 1889, issued a bulletin to the forest guards dealing with the dangerous tree diseases, in which he advised that *Ribes* and white pine should always be separated (35, p. 11). The only case of the removal of *Ribes* from the vicinity of a white-pine plantation in Europe was brought to the writer's attention at Corselitze, Denmark. The plantation referred to was located near the cottage of a forest guard, and 20 years ago an order was issued that no *Ribes* should be grown in the cottage garden. On what authority the order was issued is not known, but it is believed to have come from Rostrup. The removal of the black currants effectively checked the spread of the rust, and to-day the trees are thrifty. In contrast to this, consider the appearance of the 34-year-old white-pine plantation suffering from severe crown infection shown in

¹¹ Oral information from Skogforvalter A. Jenssen, Stavanger, Norway.

Figure 9. No control measures were attempted here, the result being that 90 per cent of the trees are diseased.

FRANCE.

French foresters to date have given the fungus little attention, for white pine is of secondary importance to them, and they have been concerned with forest problems of a nature more vital to their country. The writer found no case where the uprooting of *Ribes* had been attempted or silvicultural methods undertaken to control the disease in France. The blister rust is nevertheless working destructively in their plantations. Figure 10 shows a 17-year-old stand wherein 52 per cent of the trees are attacked so seriously that it is doubtful whether they will ever reach maturity.

BELGIUM.

Notable among recent Belgian investigators dealing with the blister-rust fungus are Professor Marchal; Professor Bommer, of Brussels; Forest Inspector Pechon; and Professor Quairiere, of the research station at Groenendaël. With the exception of the experiments made with fungicidal treatment at the experiment station at Groenendaël, the writer saw no cases where the suggested control methods have been adopted. Bommer emphasized the need of exterminating the fungus in the nurseries by destroying infected trees. Pechon in conversation with the writer placed little faith in the treatment with chemical solutions to check the development of the fungus and strongly advised the removal and burning of infected trees. Such a practice, however, is futile unless the currants and gooseberries in the locality are also destroyed.

It is a common practice in many European nurseries to grow white-pine stock and *Ribes* near each other. After attention was called to



FIG. 9.—A 34-year-old white-pine plantation at Almindingen, island of Bornholm, Denmark, in which 90 per cent of the trees have been attacked in the crown by the white-pine blister rust. Many of the trees killed by the rust have been felled. Some of the diseased trees had their weakened tops broken off by the wind.

the blister-rust menace several of the nurseries of Belgium and France specializing in conifers for exportation discontinued the growing of black currants, since this species caused the most damage to pine. In other nurseries where the currants are of major importance the cultivation of five-leaved pines has been abandoned. The nursery beds shown in Figure 11 are in one of the largest of the French forest nurseries, situated near Orleans. These were started since the war and contain Austrian and Scotch pines, but no American five-needle pines, the growing of which was discontinued.

BRITISH ISLES.

British foresters declare the rust to be altogether too prevalent, but have made no efforts to control it. The fungus has raised more interest and concern among fruit growers than it has among the foresters, because the former feared a decrease in their black-currant crop, entailing financial loss.



FIG. 10.—A 17-year-old white-pine plantation near Epinal in the French Vosges. Blister rust has attacked 52 per cent of the trees. This entire plantation is exposed to further infection from black-currant bushes growing 600 feet distant. It is doubtful whether merchantable timber will ever be obtained from it.

Trials made at Oxford, England, to check the rust by spraying *Ribes* proved quite unsuccessful (2, p. 24). Reference to the spraying of young pines with a fungicide is made in the *Quarterly Journal of Forestry* (5), with a statement that in a Belgian nursery seedlings sprayed with a 1 per cent solution of potassium permanganate had been effectively protected. Chemically treating diseased parts of stem or limb may retard the development of the disease, but results thus far obtained are rather uncertain. Silvicultural methods will never control the fungus as long as *Ribes* bushes are permitted to grow in the neighborhood, but the opinion prevails that such methods may slightly decrease the amount of infection through better aeration and the entrance of more sunlight into the stand, especially if it occupies a moist site. If the black currants had been removed from the neighborhood of the plantation at Oxford, it would not be in its present poor condition (fig. 12).

Control of a forest disease on as extensive a basis as the blister-rust work in the United States has no parallel in foreign forest practice and presents a striking contrast to the limited measures of con-

trol which they have applied to small groups or isolated ornamental specimens. Strenuous efforts to control the blister rust wherever it occurs are not made in Europe because the tree lacks the commercial status necessary to warrant such action.

No European country has carried out a definite scheme of study for the control of *Cronartium ribicola* covering a number of years. The work done in the past has been conducted by individual initiative and interest, the investigators working independently and in some cases apparently unaware of each other's activities. The work in Sweden by Eriksson was prompted by a popular fear lest the disease on *Pinus strobus* should prove a menace to the native *Pinus sylvestris*, the principal forest timber species.

GERMANY.

Klebahn's work in Germany was undertaken from a purely scientific viewpoint. He paid little attention to the practical side of the question when he saw that the foresters were not concerned about it. When the United States restricted the entry of five-needle pine nursery stock in 1912 because of the fungus, the nurserymen took a greater interest in the subject. Large nurseries situated near Halstenbeck, Germany, conducting an extensive export trade were particularly affected by this restriction. They called upon Klebahn



FIG. 11.—A large forest-tree nursery in France. The seed beds, started since the war, contain Austrian pine, Scotch pine, and Norway spruce.

to witness that their stock was free from blister rust, which testimony he was bound to decline, since the fungus is difficult to detect on seedlings. To Klebahn's knowledge measures against the disease have not been taken anywhere in Germany, since *Pinus strobus*, aside from the nurserymen's point of view, is of small economic importance. It is said that in the municipal forest of Heidelberg there are mature white-pine plantations covering nearly 150 acres. This is probably the largest single plantation of the species in Europe. Professor von Tubeuf, who has made a careful study of the blister rust in Germany, expects that in the future white pine will be grown less and less in that country.¹²

SIGNIFICANCE OF EUROPEAN EXPERIENCE TO AMERICA.

The observations made abroad on the susceptibility of sugar pine, western white pine, and the limber pine show that these species are as readily attacked and as severely damaged by the white-pine blister rust as is the eastern white pine. Laurie found western white pine

¹² Correspondence with Professor von Tubeuf, 1920.

fatally attacked at Murthly Castle, Scotland, in 1893, although no record of the occurrence was published until 1898 (26). The rust so badly damaged and disfigured the beautiful ornamental specimens



FIG. 12.—Interior view of a white-pine plantation in Bagley Wood, near Oxford, England, in which 84 per cent of the trees are in a dead or dying condition. Every tree shown is diseased, and the tree in the foreground produced spores on October 15, 1920. Black currants were growing only 100 feet away.

growing in the Murthly Castle Park, which had reached a height of 60 feet, that it was necessary to cut them down. To-day, only one tree remains of the original group of 50. This tree, having a diameter of 26 inches and a height of nearly 90 feet, is probably the

largest specimen of western white pine in the British Isles. It, too, is being killed by blister rust. In young plantations of western white pine at Balmoral Castle, Scotland, the blister rust is gradually working with telling effect. Neger reports this species as being attacked by the rust in Germany (30, p. 280).

The California sugar pine was found diseased in Scotland, France, and Belgium, and is reported from Germany.¹³ A most striking example of damage done to a single tree was observed at Murthly, Scotland. An arboretum specimen, 20 years old, with a height of 20 feet, is so heavily attacked on every limb to a height of 8 feet from the ground and so severely constricted on the stem that it is practically worthless. The late Sir Edmund Loder, of Horsham, Sussex, England, stated in correspondence that young sugar pines on his estate were attacked and killed by the rust. The appearance of infected trees in Belgium and France indicates that this species is highly susceptible.

The limber pine was seen diseased in Norway, Sweden, and France, and Tubeuf states that it is infected in Germany (42). One of the most interesting cases of damage to the limber pine by the blister rust was seen at Softeland, near Bergen, Norway. In a plantation of 7-year-old trees numbering 300, each tree was diseased and one-third of the number killed. The infection may be directly attributed to black-currant bushes growing in a garden 650 feet distant. At the Alnarp Forest nursery in Sweden 100 seedlings 6 years old were destroyed in 1920 because they were found to be diseased. A few younger seedlings remaining in the nursery (fig. 13) had developed the disease in only two cases. In the National Arboretum at Nogent sur Vernisson, France, 12-year-old trees of this species have been killed by the disease (fig. 14).

The Mexican white pine is heavily infected, the disease being found on this species in Belgium and England. Extensive plantations of these trees do not exist abroad, since they have been planted chiefly for ornamental purposes. The severity with which the fungus has attacked them and its rate of development clearly demonstrate that they are readily susceptible.

These facts are of special significance to the United States and sound a clear call to action. The recent discovery of white-pine blister rust in British Columbia and Washington and the widespread abundance of wild currants and gooseberries in the Pacific coast and Rocky Mountain regions (there being about 60 species) place the valuable western five-needle pines in an extremely hazardous position. Furthermore, climatic conditions of the West appear to be favorable to the spread and development of the fungus. There is a striking resemblance between the climate of western Norway, where the disease worked destructively in white pine and limber pine, and the northwest coast of the United States. Observations in Norway on the growth of the Douglas fir and Sitka spruce show that these indigenous species grow admirably in that region, thus giving evidence of the similarity of the climate of the west coast of Norway and of America. They give such promise of excellent volume production that in the future these trees will undoubtedly play an important rôle in the forestry practice of that country.

¹³ Correspondence with Professor von Tubeuf, 1920.

During the wet summer of 1917 (2, p. 24) the blister rust developed so heavily and so seriously on cultivated black currants in England that nurserymen became alarmed and feared a decided setback to their currant crop because of defoliation of the bushes.¹⁴ A climatic condition favorable to the spread of the rust on the currants results in an increased amount of pine infection. French

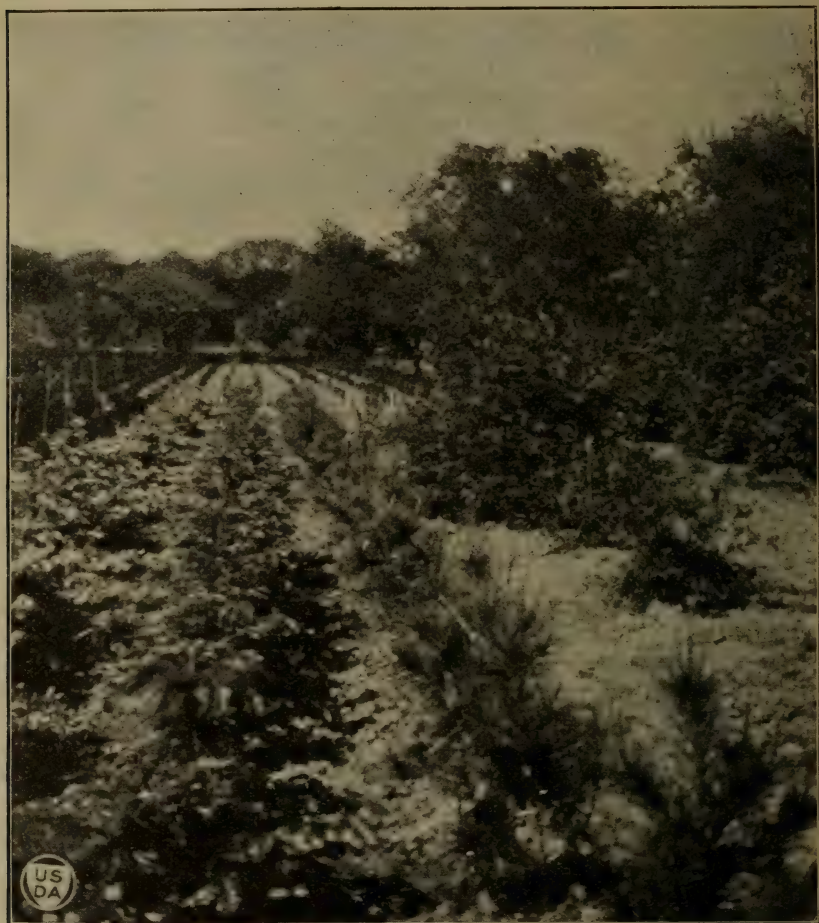


FIG. 13.—Limber pine (*Pinus flexilis*) growing in a nursery at Alnarp, Sweden. Blister rust first appeared here in 1920, at which time 100 seedlings 6 years old were destroyed. The young trees were growing within 300 feet of black currants and gooseberries. This shows the results that may be expected from an exposure of this species to the white-pine blister rust.

foresters maintain that the disease is much more abundant during a wet year than in a dry one.¹⁵ A similar opinion is upheld by members of the Belgian forest service. In the western United States the two factors of an abundance of wild currants and gooseberries and a climatic condition favorable to the fungus will work together to the detriment of the five-needle pines. European cli-

¹⁴ Notes obtained from Kew Garden Laboratory, through the courtesy of Dr. A. D. Cotton.

¹⁵ Oral statement to the writer.

matic conditions suitable to the growth of the five-needle pines were found favorable to the development of the blister rust.

ECONOMIC ASPECTS OF THE BLISTER-RUST PROBLEM.

The problem of controlling the blister rust in eastern North America is distinctly an economic one, and the practical application of forest pathology must aid in the protection of a basic industry by maintaining forest production. The task at present has developed beyond protecting merely a restricted area; it involves the entire country west as well as east. It has been positively demonstrated in eastern North America that this disease can be controlled at a reasonable cost by uprooting all currant and gooseberry bushes within 900 feet of white-pine forests. The blister rust can not be eradicated from North America, but the local destruction of currants and gooseberries prevents damage to pines within the control area.

The value of the commercial eastern white pine alone amounts to \$276,000,000¹⁶ an asset well worth insuring against the rust. Recent careful studies made on the rate of spread of the fungus in New York, New Hampshire, Vermont, and Massachusetts show 15 per cent general infection. This is only the beginning of the invasion, for the disease is comparatively young here, having been only 25 years in the country and not imported to any appreciable extent until 1909. During the next decade it will gain impetus, spread with ever-increasing force, and impress its seriousness upon the public mind. The crux of the situation lies in the fact that the young white-pine growth which should become the commercial stands of the next 30 years will be severely hit. Clearly the control of the disease by the removal of currants and gooseberries in the East must be vigorously pursued.

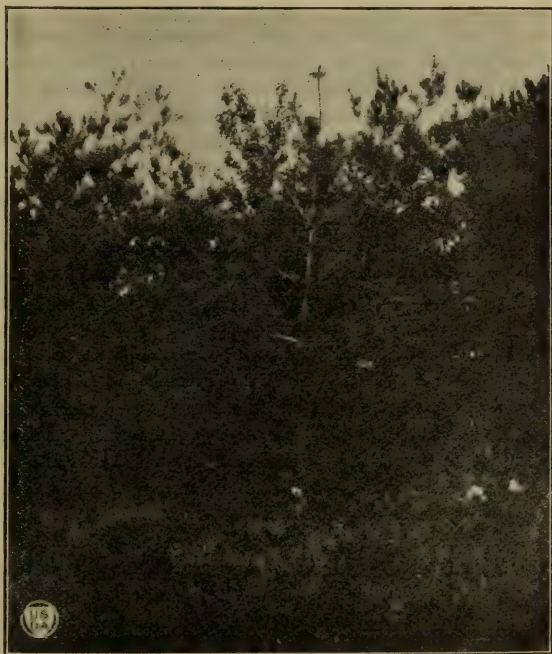


FIG. 14.—Limber pine (*Pinus flexilis*) in the National Arboretum at Nogent sur Vernisson, France, dying from a blister-rust attack. The 12-year-old tree in the center was much weakened in 1920, as indicated by the yellowing and shedding of the needles, and died the following year. This species appears to be a ready victim to the rust.

¹⁶ Estimate of the United States Forest Service.

WESTERN NORTH AMERICA.

One of the grave problems now confronting the Federal and State Governments is the safeguarding of the five-leaved pines of the West from this European pest. Now that the disease has made its appearance in British Columbia and Washington, what will be the result? The final outcome is difficult to forecast, but it is certain that the western five-leaved pine forests are in grave danger. Observations made in Europe upon the susceptibility of sugar pine, western white pine, and limber pine to the fungus showed that these trees are as readily attacked and as severely damaged by the white-pine blister rust as is the eastern white pine. It means that \$228,400,000¹⁷ worth of growing timber is to become the prey to a very insidious and dangerous disease. A widespread attack in this region is imminent and threatens to bring immeasurable loss to private owners as well as to the Federal Government. To judge from the severity of the disease on these species of pines in Europe, it is no exaggeration to predict that the presence of the blister rust in the Northwest threatens the future position of these valuable pine species in the timber markets of the world.

DECIDED STEPS OF ACTION NECESSARY.

The action demanded by present conditions in order to control the blister rust is summarized as follows:

(1) Energetic control of the disease in the East by the general eradication of currants and gooseberries in pine-growing sections.

(2) Prompt and decisive action to control the disease in the West.

(3) Eradication of the cultivated black currant, the most susceptible alternate host of the blister rust and the most active agent in its spread and establishment.

(4) Strict adherence to and prosecution of the quarantine laws prohibiting the shipment of five-needle pines and currant and gooseberry plants from infected territory. Also the continued enforcement of the quarantine placing an absolute embargo on foreign nursery stock, thus preventing the entrance of the blister rust and other pests from foreign countries. Conditions demand such action.

The scope of the problem is more than regional or national; it is international. Neither evasion of the quarantines nor laxity in the prosecution thereof can be permitted. The liability is large and the hazard great.

SUMMARY OF THE BLISTER-RUST SITUATION IN EUROPE.

The white-pine blister rust was first discovered some 65 years ago on pine and currants in the Baltic Provinces of Russia. Six years later it was seen to attack seriously 30-year-old white-pine trees in Finland and was marked as a dangerous tree disease. It is difficult to state where the disease originated, but the facts available to the writer indicate that Russia was the original home and *Pinus cembra* its host. From there it migrated and gradually spread over western Europe.

Its occurrence was noted with increasing frequency from 1880 to 1900, particularly in those countries, such as the British Isles, Denmark, Germany, and Sweden, in which plant pathology is carefully

¹⁷ Estimate of the United States Forest Service.

studied and in which tree species from America were being continually sought for experimental forest planting and ornamental purposes.

The first known occurrence of white pine in Europe was in the Royal Nurseries at Fontainebleau, France, in 1553. It was not extensively planted until after its first introduction into England in 1705 and later into other European countries. From the outset it gained the high regard of arboriculturists and foresters abroad because of its distinct ornamental beauty and the excellence and suitability of its wood for many purposes. To-day it is well known in Europe, having been one of the most widely distributed of the introduced American trees.

Nurseries undertook the cultivation of white-pine stock for domestic sale and for export trade in localities where currant and gooseberry bushes were present, a practice which contributed largely to the spread of the fungus in Europe and America. As the demand for nursery stock increased, European nurseries, particularly those of Germany and France, undertook to meet the requirements. Until 1912 they could raise and ship white pines to America without restriction. This policy resulted in the importation of the white-pine blister rust into America about 1898, and this plague gradually spread through the northeastern white-pine region. Later, probably about 1910, it was introduced into British Columbia and has recently reached Washington.

The spread of the blister rust followed the increase in the distribution of white pine in European countries, reaching even to the northernmost plantings of the species in Norway. Eastern white pine is not the only member of the American five-leaved pine group attacked by the blister rust. Other five-leaved pine species introduced into Europe for ornamental and experimental planting have likewise become affected. Prominent among these are the California sugar pine, the western white pine, the limber pine, and the Mexican white pine. These species appear to be as readily susceptible as the eastern white pine.

Cultivated black currants and gooseberries, especially black currants, are very plentiful in European countries, and through them the disease is perpetuated with ever-increasing volume. Wild currants and gooseberries are very limited as to the number of species, and the bushes are scarce in the forests. The control of blister rust as a forest-tree disease does not appear to have been seriously attempted abroad. A few efforts have been made to check the fungus on individual ornamental trees by removing the infected parts or treating them with chemical solutions. The wholesale removal of cultivated and wild currants and gooseberries is not practiced, not because of lack of knowledge of the damage done by the diseased currants, but because the currants are of more value to the people than the foreign white pine.

The blister rust is gradually driving the white pine out of Europe. Unfortunately, the stands are gradually disappearing in Europe because of damage by the blister rust. Foresters generally are expressing the opinion that the damage done by the fungus is too large to permit raising the species at a profit. Often over 90 per cent of the trees in plantations are infected, and frequently one-third have been killed by the blister rust. Mature trees also are fatally attacked, as

shown on eastern white pine in Sweden and France and western white pine in Scotland. Many European foresters have been enthusiastic over the future prospects of white pine in their countries, believing that it would come to occupy an important position in their system of management and be regarded as an indigenous species. As shown by its growth abroad it has excellent volume production, regenerates well (fig. 15), and is not exacting as to soil and moisture requirements. Such an optimistic outlook was held by foresters in Denmark, Belgium, and Norway, while the Germans had faith enough in the productive capacity of the species to plant considerable areas with white pine.



FIG. 15.—Natural white-pine reproduction in the communal forest of La Mouche, Epinal, France. In this part of the forest 36 per cent of the young trees were attacked by the blister rust, thus greatly reducing the probability of a future crop.

Other foreign conifers, such as Douglas fir, Sitka spruce, and Japanese larch, will gradually replace the disappearing white pine. Himalayan and Balkan pine will also come into more extensive use for forest planting.

EUROPEAN EXPERIENCE A WARNING TO AMERICA.

This disease is a most dangerous forest enemy. It readily kills mature trees, but the greatest menace is in sweeping out of existence the young pine stock of to-day which is to become the mature timber of to-morrow. Although it is slow in developing, it is nevertheless constant in action and certain in destruction, undermining the very security of our forest capital, without which continued forest production is impossible.

Blister-rust control is a national problem. It is necessary to protect a resource so essential as white pine for economic and industrial development. Simple and practical methods are available to any pine owner in the eastern United States which enable him to safeguard his pines from this disease. The blister rust is spreading into the western white-pine and sugar-pine forests and threatens the commercial extinction of these species. Vigorous action is required to develop and apply measures that will minimize the damage in the West.

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WHITE-PINE BLISTER RUST may destroy much of the white pine of the United States. This destructive disease probably had its original home in Asia, later reaching Europe. It was introduced into America during the years 1898 to 1910. European and American investigations indicate that this rust can not spread direct from pine to pine and that an intermediate stage of development on currant and gooseberry bushes is necessary before it can harm the pine. Studies of the disease in this country showed that the distance to which currant and gooseberry bushes infect pines is comparatively short. This knowledge is the basis of the local control work in the United States, which was begun experimentally in 1916. These experiments prove that under ordinary forest conditions in the eastern United States a stand of white pine is subject to little or no damage from the rust if there are no European black currants growing within a mile and no other currant or gooseberry bushes within 900 feet. European black currants are dangerous to pine at greater distances than other species because they are more susceptible to the rust and produce a much larger volume of spores per unit of infected leaf surface.

The purpose of the study in western Europe in 1919-20 was to determine how destructive the blister rust had been to American white-pine species planted abroad and what steps, if any, had been taken to combat this disease in foreign countries that would be of practical value in controlling the disease in the United States. It was found that cultivated black currants and gooseberries, especially black currants, are very abundant in Europe and popularly considered of more value than the foreign white pine. Consequently these bushes have not been removed from the vicinity of the white-pine plantations, and the blister rust is gradually driving these trees out of Europe by destroying such a large percentage that it is unprofitable to cultivate the species. White pine is being supplanted by other foreign conifers, such as Japanese larch, Douglas fir, Sitka spruce, and Balkan pine.

Very recently the blister rust has been found on the Pacific coast in Washington and British Columbia. This discovery is a matter of great concern, since there are seven different white-pine species in the West and the country's greatest white-pine resources are centered in the western white-pine and sugar-pine forests. Western white pine and limber pine apparently are more susceptible to the blister rust than eastern white pine. Sugar pine is also highly susceptible. To delay the spread of the rust through the eradication of cultivated black currants and quarantine enforcement and the development of practical local control measures adapted to the conditions found in western forests are the only alternatives to the ultimate extinction of the most valuable commercial pine-timber species of the West.

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EFFECT OF KILN DRYING, STEAMING, AND AIR SEASONING ON CERTAIN FUNGI IN WOOD.¹

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[In Cooperation with the Forest Products Laboratory of the Forest Service.]

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INTRODUCTION.

Among lumbermen and kiln-drying experts the belief is general that the temperatures and humidities used in the various commercial kiln runs and steaming processes, with the exception of stock that requires low temperatures and high humidities, are efficient in killing the various stain and decay producing fungi found in lumber and other wood products. Accurate tests to support this belief have never been made. It was the object of this study to determine whether the fungi in lumber are killed under ordinary commercial kiln conditions and steaming processes and to gain some idea of the minimum time and temperature limits necessary to kill these organisms. Such information has a wide application in the steaming processes commonly applied to gum, poplar, and other hardwoods previous to air seasoning and to the steaming of billets in the cooperage and other industries. It also has a very important bearing upon the sterilization of ties, posts, and poles and of mine, bridge, and building timbers when treated by a preservative process where

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Acknowledgments are due to Miss A. M. Waterman for aid in culturing some of the test blocks; to members of the section of timber physics, Forest Products Laboratory, for aid and advice in handling the dry kilns; and to Dr. C. J. Humphrey for advice in outlining the project and furnishing samples of infected wood.

heat is introduced as a preliminary steaming or during impregnation, or both.

The application of heat as a method of sterilization has a wide field. In most of the kiln-drying and steaming processes now in use where sufficiently high temperatures are used it serves the double purpose of seasoning and sterilizing the wood. However, in many of the steaming processes used primarily for the purpose of softening the wood little or no attention is paid to the sterilization of the stock. Adjustments in temperatures and periods of heating may not only result in the killing of such fungi present in the wood before treatment but may prove beneficial in rapidly drying the surface of the wood during subsequent air seasoning and thus aid in the prevention of sap stains, molds, and decay. The slack cooperage industry presents among others one notable case for experimentation along these lines.

In the preservative treatment of wood where heat is used during the process the sterilization of the inner portions of the wood not penetrated by the preservative is often desirable. Very often ties, posts, poles, and timbers of various kinds contain before treatment certain active decay organisms which are fully capable of reviving under favorable conditions, continuing the decay process, and eventually weakening the wood. Sterilization would not only greatly reduce the chances of loss from such a source, but would make it possible to utilize for less exacting purposes material containing to a limited extent certain types of incipient decay.

In this connection it is necessary to take into account several factors, among which the efficiency of the preservative, the relative absorptivity, and the strength qualities of the infected wood are paramount.

In the control of blue stain in lumber the use of chemical dips can at best protect only the surfaces of the wood against the stain organisms. In case the fungus is already present in the log before it is sawed into boards the dip solution has no effect upon the fungus within the board. Heat treatment in conjunction with the chemical action therefore would greatly increase the protection against blue stain.

Steaming is the common method of applying heat in most of the commercial operations connected with the production and manufacture of wood, although electricity may be used effectively in some cases. Directing an electric current through wood has been tested in this country, in France, and in Australia as a rapid method of seasoning,² and it is conceivable that the electric current may be used to advantage in the sterilization of wood, particularly as a means of checking incipient decay of structural timbers in buildings, ships, bridges, or other structural units where it may be found impracticable to apply other means of heating.

PREVIOUS WORK.

Both Hoxie (2)³ and Snell (8, 9) have contributed to the subject of the effect of heat on fungi in wood. Hoxie tried the experi-

² Menzel, C. A. Preliminary experiment in the drying of wood by passing an electric current through it. U. S. Dept. Agr., Forest Serv., Forest Products Lab. Unpublished manuscript, 1921.

³ The serial numbers (*italic*) in parentheses refer to "Literature cited," at the end of this bulletin.

ment of heating a mill, the timbers of which were infected with dry rot, to about 115° F. The heat was applied from Saturday noon until Monday morning on four different occasions. Hoxie states that specimens were cultivated from 40 of the badly rotted beams and only 4 showed living fungi. The fungus in this case was given as *Merulius lachrymans*, which is particularly sensitive to heat. Snell, using $\frac{3}{4}$ -inch blocks of spruce artificially inoculated with *Lenzites sepiaria*, *Lenzites trabea*, *Trametes serialis*, *Lentinus lepideus*, and *Trametes carnea*, respectively, subjected these blocks to both moist and dry heat at varying temperatures and periods of time. The results of his tests indicate that moist heat is much more effective in killing the fungi than dry heat. None of the fungi within these blocks were able to withstand 131° F. for 12 hours at moist heat, while it took a heat of 221° F. for 12 hours to kill all the fungi with dry heat. The experimental data are limited to tests on $\frac{3}{4}$ -inch blocks, but statements are made that the temperatures employed in the kiln drying of lumber and in the various wood-preservation processes are sufficient to kill any fungi within the wood.

MATERIAL USED IN THIS STUDY.

The first lot of material consisted of 18 pulp logs of northern white spruce (*Picea canadensis*)⁴ shipped in from northern Wisconsin. Six wood-destroying fungi were found infecting this material. In some cases the rots of two fungi were present in the same log; as, for example, *Polyporus anceps* in the sapwood and *Trametes carnea* in the heartwood, a faint colored zone showing at the junction of the two kinds of rot.

The second lot consisted of a carload of mixed hardwood and conifer logs 16 feet long shipped in from the Menominee Indian Mills, Neopit, Wis. These logs were selected by the writer from standing green trees on the logging area. An attempt was made to find trees with fruiting bodies of the attacking fungus attached, but this was not possible in all cases. A total of 23 logs representing 9 hosts and several wood-destroying fungi comprised the shipment, a detailed list of which is given on a succeeding page. The blue-stain fungus (*Ceratostomella* sp.) was found in three of the hosts and *Torula ligniperda* in two hosts. Dark brownish and black discolorations extending the full length of the log were found bordering the incipient decay of the brown cubical rot of tree No. 3 (eastern white pine) and trees Nos. 8 and 9 (eastern hemlock). Upon examining sections of the dark-colored wood under the microscope, typical spore chains of *T. ligniperda* were observed within the wood cells. The association of this stain-producing fungus with typical wood-destroying fungi in decaying wood is apparently quite general (6).

At the laboratory sawmill, disks 3 inches thick were cut from the middle point of each log. These disks were numbered and the decay area sketched upon record cards. Photographs taken of some of these disks show the types of infection. (Pl. I.)

There was some doubt as to the identity of the fungus causing the rot in tree No. 18, basswood (*Tilia americana*). The butt log showed a slight hollowing at the base, and within this hollow there

⁴ Authorities for the scientific names are given in the list on page 4.

developed during storage several large yellow-colored mushrooms, tentatively determined as a species of *Pholiota*. Later, a block of the rotted wood was placed in the humidity room and kept moist. In about a month several typical sporophores of *Pholiota adiposa* were produced (Pl. II). Typical sporophores have also been produced on malt-agar cultures.

The third lot of infected logs consisted of a carload shipment of Douglas fir (*Pseudotsuga taxifolia*) and incense cedar (*Libocedrus decurrens*) shipped by Dr. J. S. Boyce from Oakridge, Oreg. The Douglas fir logs contained rots caused by *Trametes pini*, *Polyporus schweinitzii*, and *Fomes laricis*. The incense-cedar logs contained the rot caused by *Polyporus amarus*. The shipment consisted of 32 logs each 16 feet long, the total scaling 7,790 feet, board measure.

A few logs of *Alnus oregona*, intended for pulping experiments but rejected when found infected with *Polystictus hirsutus* and *Polystictus versicolor*, were also used in the study, as well as some miscellaneous material listed on the following pages.

List of fungi and hosts.

Shipment from Port Edwards, Wis.:

Polystictus hirsutus Fr. in northern white spruce (*Picea canadensis* (Mill.) B. S. P.).

Polyporus anceps Pk. in northern white spruce.

Lenzites sepiaria Fr. in northern white spruce.

Trametes carnea Nees. in northern white spruce.

Polystictus abietinus Dicks. in northern white spruce.

Trametes pini (Thor.) Fr. in northern white spruce.

Fomes pinicola Swartz in northern white spruce.

Miscellaneous material:

Polyporus anceps Pk. Murr. in western yellow pine (*Pinus ponderosa* Laws.).

Polystictus hirsutus Fr. and *P. versicolor* Fr. in red alder (*Alnus oregona* Nutt.).

Blue stain in *Liquidambar styraciflua* L.

Alternaria sp. in *Pinus rigida* Mill.

Trametes pini in *Pinus banksiana* Lamb.

Shipment from Neopit, Wis.:

Trametes pini in larch or tamarack (*Larix laricina* (Du Roi) Koch).

Brown cubical rot in white pine (*Pinus strobus* L.).

Ceratostomella pilifera Fr. and *Torula ligniperda* (Willk.) Sacc. in white pine.

Brown cubical rot in northern white cedar (*Thuja occidentalis* L.).

Blue stain in northern white cedar.

Brown ring-rot in northern white cedar.

Fomes pinicola in hemlock (*Tsuga canadensis* (L.) Carr.).

Torula ligniperda (Willk.) Sacc. in hemlock.

Brown cubical rot in hemlock.

Ganoderma tsugae Murrill in hemlock.

Fomes fomentarius Fr. in paper birch (*Betula papyrifera* Marsh.).

Fomes igniarius (L.) Gillet in white elm (*Ulmus americana* L.).

Trametes pini in white pine.

Brown cubical rot in northern white cedar.

Fomes igniarius in red maple (*Acer rubrum* L.).

Trametes pini in larch (*Larix laricina*).

Pholiota adiposa Fr. in basswood (*Tilia americana* L.).

Polyporus borealis in sugar maple (*Acer saccharum* Marsh.).

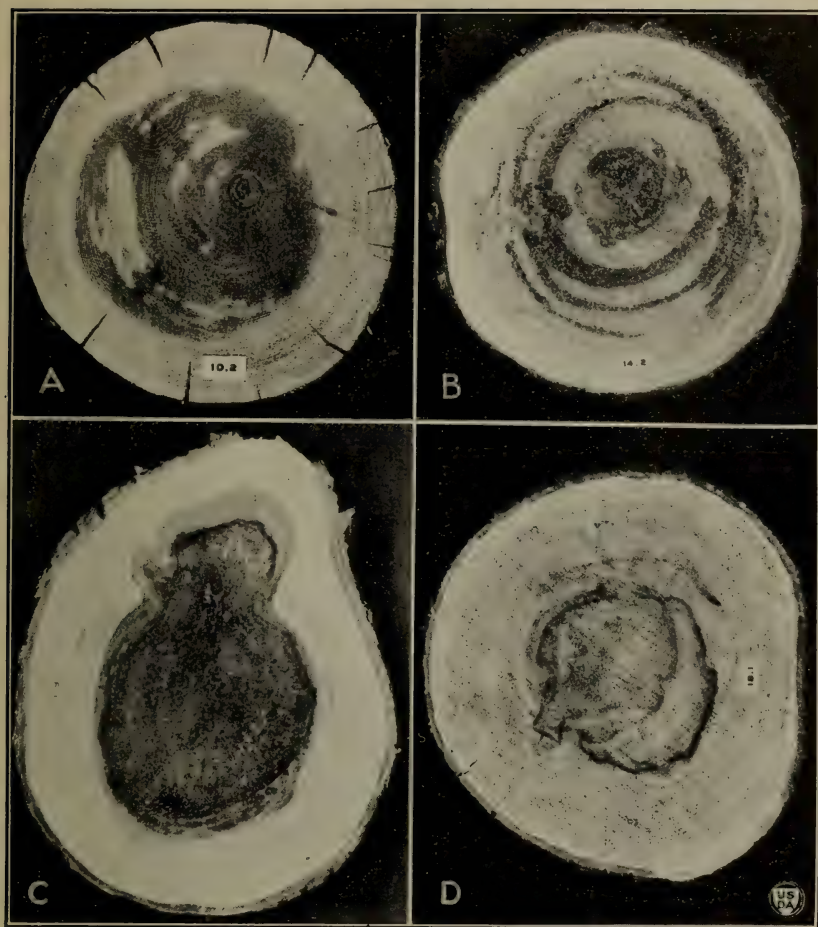
Shipment from Oakridge, Oreg.:

Trametes pini in Douglas fir (*Pseudotsuga taxifolia* (Lam.) Britt.).

Polyporus amarus Hedg. in incense cedar (*Libocedrus decurrens* Torr.).

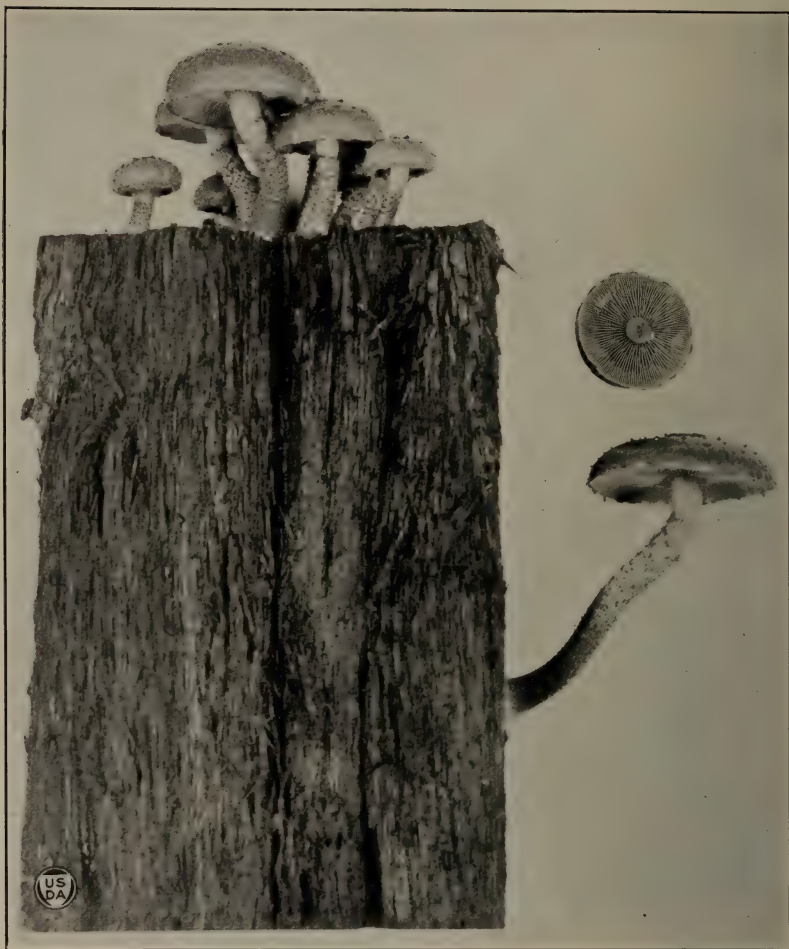
Polyporus schweinitzii Fr. in Douglas fir.

Fomes laricis (Jacq.) Murr. in Douglas fir.



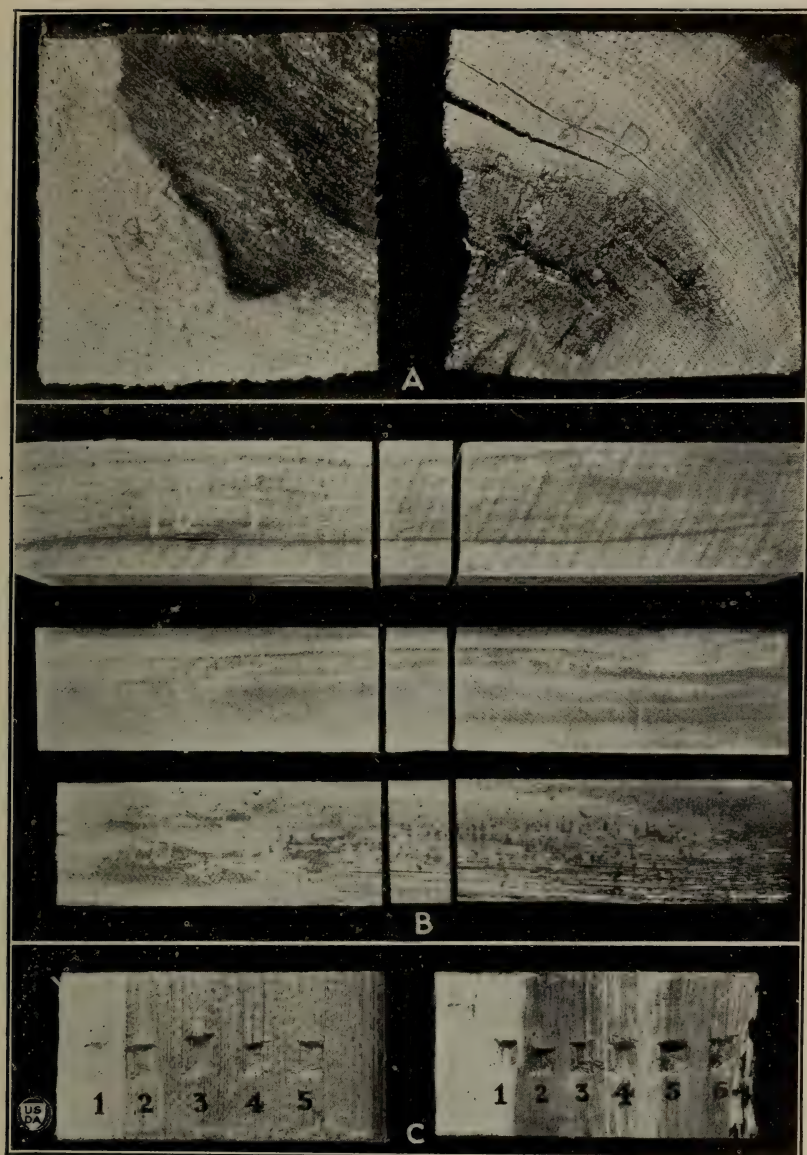
TRANSVERSE SECTIONS OF HEMLOCK, WHITE PINE, SOFT MAPLE, AND BASSWOOD, SHOWING ROTTED AREAS.

A, Transverse section of a hemlock (*Tsuga canadensis*) log from tree No. 10, showing the incipient stage of rot produced by *Ganoderma tsugae*. B, Transverse section of a white pine (*Pinus strobus*) log of tree No. 14, showing the ring-rot of *Trametes pini*. C, Transverse section of a soft maple (*Acer rubrum*) log of tree No. 16, showing the incipient and typical stages of *Fomes igniarius*. The dark area surrounding the central rotted area is the incipient region. D, The transverse section of a basswood (*Tilia americana*) log of tree No. 18, showing the incipient rot produced by *Pholiota adiposa*. Note the darker outer zone of discoloration.



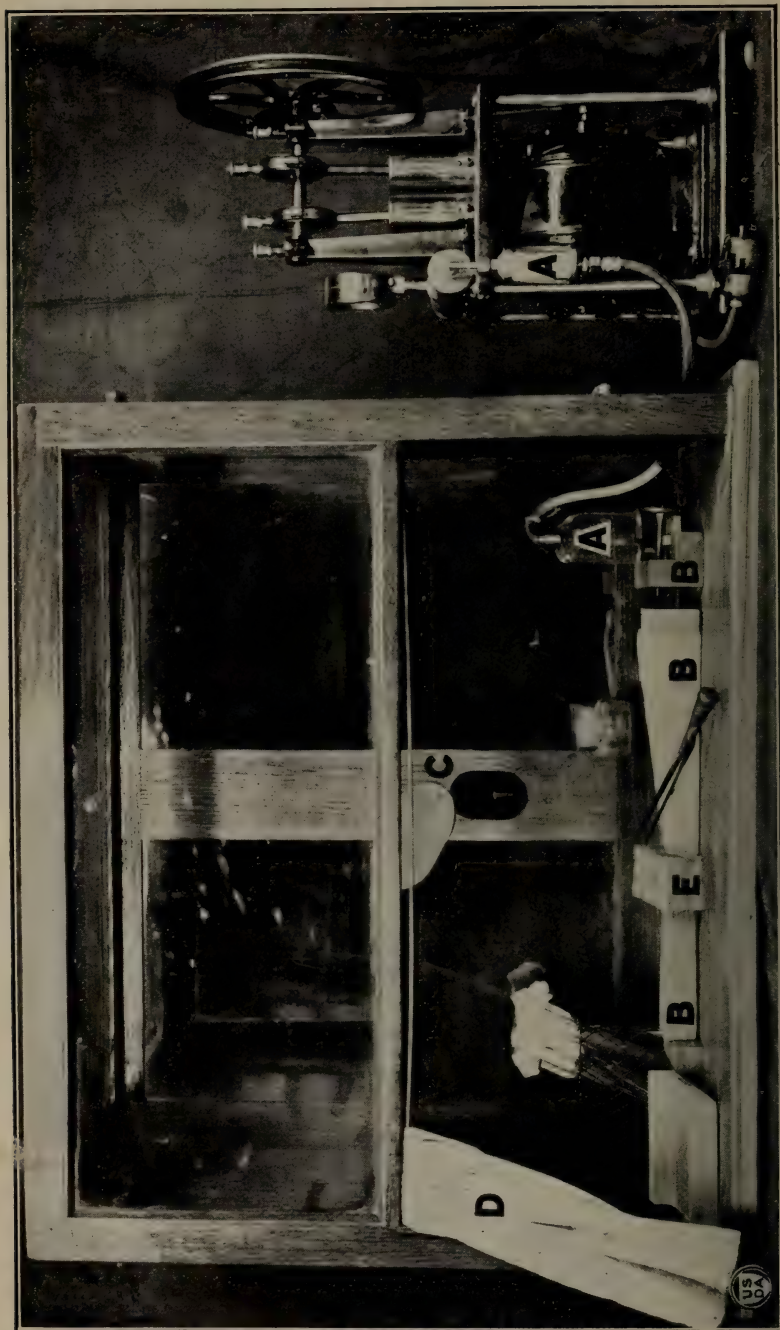
BASSWOOD INFECTED WITH PHOLIOTA ADIPOSA.

Sporophores of *Pholiota adiposa* produced on a piece of infected basswood (tree No. 18) which was placed in a moist chamber for one month.



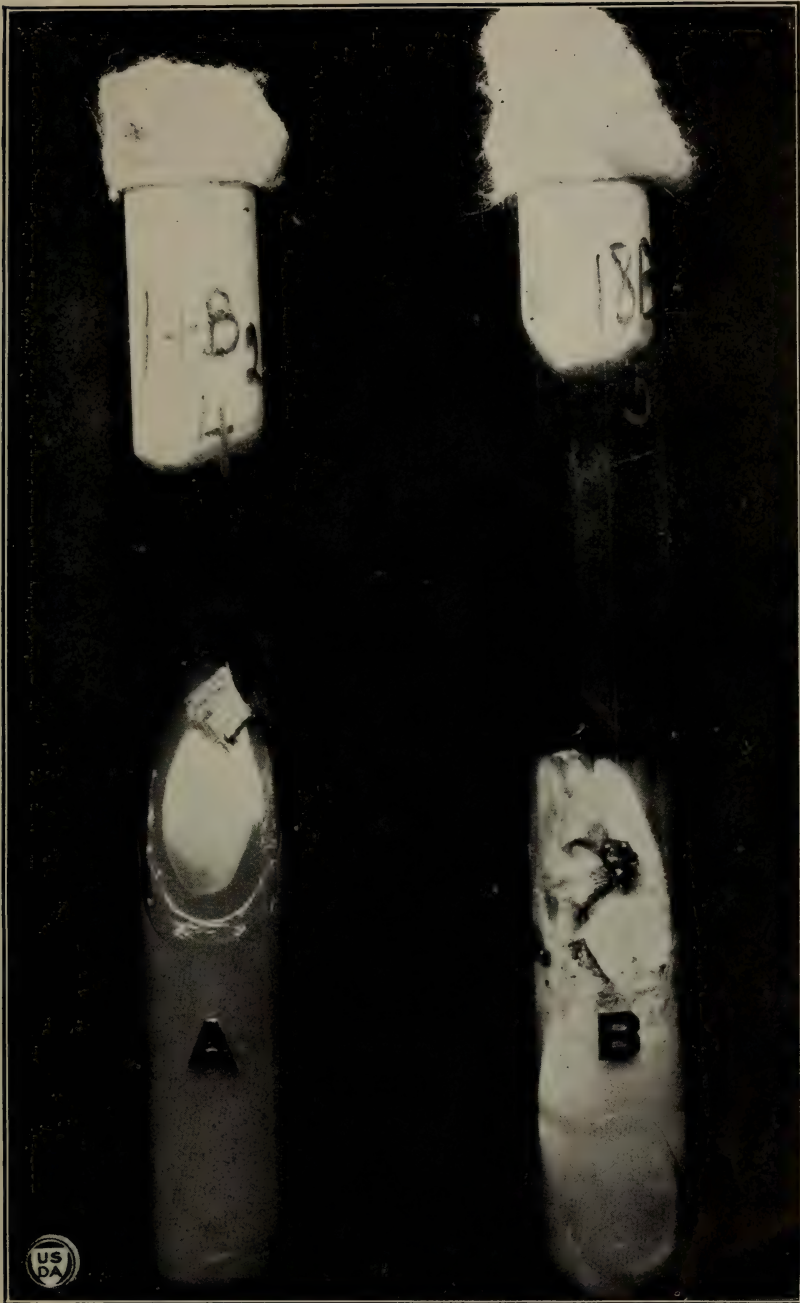
TIMBER TEST PIECES ILLUSTRATING THE METHODS OF STUDY.

A, Culture blocks cut from test pieces Nos. 8D and 18D, showing the distribution of the rots in the central portions of two 4 by 4 inch test pieces. The incipient stage of each rot is seen to extend into the center of each. B, Culture blocks cut from the center of 1-inch (lower), 2-inch, and 4-inch (center and upper) test pieces from tree No. 18. C, Culture blocks showing the hollows where fragments have been removed with the chisel forceps.



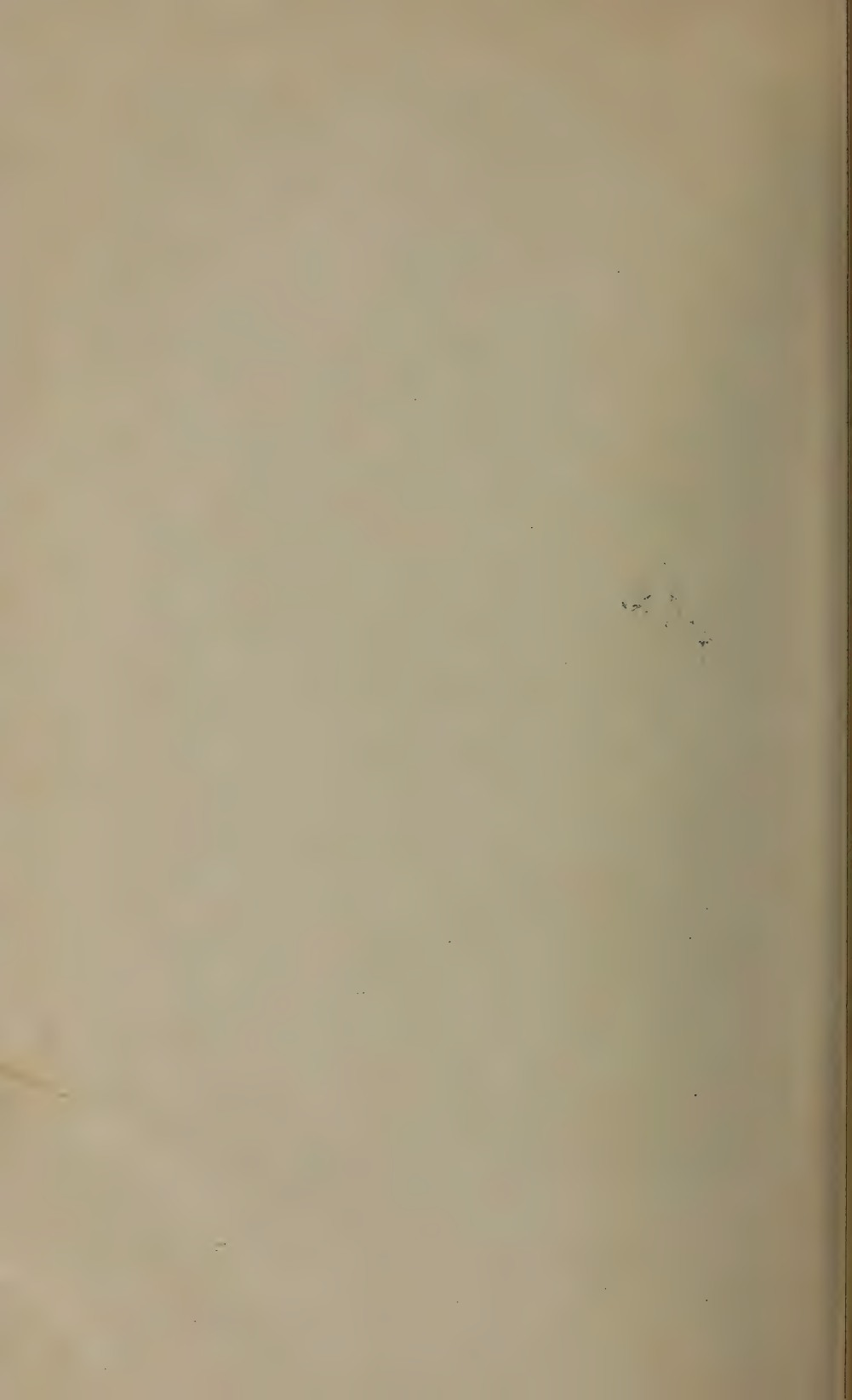
SPECIAL CULTURE CASE AND EQUIPMENT USED IN MAKING CULTURES FOR THE TESTS.

A, Atomizer filled with either distilled water or an antiseptic solution attached to an electrically driven air pump and used to spray the interior of the culture case. B, Parts of the clamp used to hold the culture block. C, Opening in the rear of the case which permits the sterilization of instruments and the flaming of test tubes with the gas flame outside of the case. D, Cloth curtain with armholes and sliding on a rod. E, Culture block from which fragments of infected wood are removed with the chisel forceps shown at the right. F, Electric switch used in starting and stopping the pump.



CULTURE TUBES SHOWING NEGATIVE AND POSITIVE RESULTS.

A, Culture tube showing a negative result; no fungous growth has developed from the fragment of wood. The white area on the surface of the agar is due to reflections of light. *B*, Culture tube showing a positive result; the fungus has grown from the fragment of infected wood, and a small sporophore (*Pholiota adiposa*) has developed.



METHODS OF STUDY.

The logs and other pieces assembled for this study were cut into test pieces at the sawmill of the Forest Products Laboratory under the direct supervision of the writer. The 16-foot logs were first cut into 8-foot logs. A 3-inch disk was then cut from one of the 8-foot logs. (Pl. I.) The 8-foot logs were divided into imaginary 4-foot bolts and lettered A, B, C, D, etc., beginning at the first bolt at the base of the first log taken from a tree. The tree number was used in conjunction with these letters in labeling the bolts, the planks, and the test pieces cut from each. For example, the first 4-foot bolt in tree No. 14 was labeled 14A, the second 14B, and so on, including the second and third 16-foot log. The 8-foot logs were cut into 2-inch and 4-inch planks, and an attempt was made to include the maximum quantity of incipient decay in each plank. The planks from each log were numbered consecutively, and records were thus made, showing the position of each plank in the log. Diagrams of the longitudinal extent of the rot in each plank were also made. The planks were next cut into the required sizes for test pieces, 1 by 4 by 24 inches, 2 by 4 by 24 inches, 4 by 4 by 24 inches. These are referred to in this bulletin as 1-inch, 2-inch, and 4-inch stock. These test pieces were numbered and sorted. In cutting the test pieces care was taken to include in each piece a maximum of the incipient stage of decay. Incipient or typical decay extending from the edge to the center of the piece constituted the minimum requirements. (Pl. III, A.)

A series of preliminary cultures was next made, using fragments of infected wood taken from test pieces cut from each of the logs. This was done to test the vitality of the fungous mycelium within the infected wood.

The sets were open piled, using half-inch to 1-inch crossing sticks between layers, thus providing free circulation of air about the pieces and about the piles.

CULTURAL METHODS.

Upon the removal of the test pieces from the kiln, culture blocks 2 inches thick were cut from the center of each piece. (Pl. III, B.) These were given the piece number and placed in boxes to await culturing. The culture work called for special equipment in order to handle more efficiently and speedily the large number of cultures. A special culture or transfer case (Pl. IV) was constructed with motor-driven spray apparatus (Pl. IV, A, F), special clamp for holding the culture blocks (Pl. IV, B), an opening in the rear of the case allowing the instruments used to be sterilized over a gas flame placed on the outside of the case near the opening (Pl. IV, C), and a sliding cloth curtain (Pl. IV, D), which allowed the free use of the hands during the operations.

The cultural process in detail is as follows:

A culture block is selected and quickly dipped in a solution of 1 to 1,000 mercuric chlorid; it is then split open along a central line with a sterilized hatchet blade. After the interior of the case has been thoroughly sprayed with distilled water or an antiseptic solution, half of the block is clamped as shown in Plate IV, E. The chisel forceps is next sterilized by dipping it in 95 per cent alcohol and flaming over the gas jet. The fragments of

infected wood are then cut and pried out of the block with this instrument and placed in sterile test tubes containing plain malt agar. The area from which each fragment is removed is numbered and the test tube containing it is similarly marked. The block when removed from the clamp shows the numbered hollows (Pl. III, C) and their distribution over the face of the block. A sketch was made of the split block, showing the areas from which fragments were removed, indicating the stages of decay and the limits of the discolored areas.

A large percentage of the cultures are contamination free, and an average of 96 to 100 tube cultures can be made in two hours. When three out of six tubes showed contamination, or when results seemed doubtful, the cultures were repeated.

Plain malt agar⁵ was used in the tubes and the surface of the agar slanted. All cultures were grown at room temperatures and were kept for a minimum period of six weeks, in order to observe the negative cultures and watch for delayed revival of the fungi in the inoculum. A negative culture is shown in Plate V, A, and a positive culture in Plate V, B.

KILN-DRYING AND STEAMING EXPERIMENTS.

RUN 1.

A set of test pieces of the Neopit and Oakridge material was placed in a small experimental dry kiln for a period of 16 days.

The temperature range during the run was from 120° to 135° F. The relative humidity averaged 85 per cent during the test, with a range between 100 and 70 per cent.

Cultures made from the blocks removed from the test pieces at the end of the run showed all the fungi to be dead within the centers of all the 1-inch, 2-inch, and 4-inch pieces.

RUN 2.

Eighteen spruce (*Picea canadensis*) pulp logs received from northern Wisconsin were sawed into test planks 2 by 10 by 48 inches. These logs were infected in the storage pile by various wood-destroying fungi, and in most cases both the typical stage and the incipient stage of decay were included in the test planks. In many cases the rots of more than one fungus were present in the same test plank.

A set of 20 planks was placed in a Tiemann dry kiln along with a commercial run of 2½-inch bald cypress lumber for a period of 40 days. Three planks of western yellow pine (*Pinus ponderosa*) infected with *Polyporus anceps* and 15 pieces from the Neopit material were also added. The initial temperature was 95° and the end temperature 160° F. During the kiln drying the relative humidity ranged between 50 and 84 per cent. At the end of the run, culture blocks were cut from the center of each plank. Cultures were made in the usual manner, and it was found that all the fungi had been killed.

RUN 3.

A set of test pieces of the Neopit and Oakridge material combined was placed in a Tiemann dry kiln for a period of 12 days. The set was placed on top of a charge of oak lumber.

The temperature range during the run was from 143° to 168° F. The relative humidity averaged 57 per cent during the run, with a range between 28 and 95 per cent.

⁵ Distilled water, 1,000 cubic centimeters; Trommer malt extract, 25 grams; agar (powdered), 15 grams.

The fungi were found to be dead within the centers of all the 1-inch, 2-inch, and 4-inch pieces.

RUN 4.

A set of test pieces of the Neopit material was placed in a Tiemann dry kiln for a period of 18 days. The set was placed on top of a charge of 1-inch commercial birch lumber. The temperature range during the run was from 135°, the initial temperature, to 180° F. The range in relative humidity was from 50 to 85 per cent. On the seventeenth day of the run the charge was conditioned for 20 hours at 180° F. and 85 per cent relative humidity.

At the end of the run, cultures made from these blocks showed all the fungi to be dead within the center of each test piece.

RUN 5.

(a) Six green 1-inch sap gum (*Liquidambar styraciflua*) boards showing blue stain were subjected to 30 pounds of steam, gauge pressure at approximately 274° F., for a period of 40 minutes in a Kraetzer preparator. Samples containing blue stain were cut from these boards after the treatment and forwarded from Memphis, Tenn.

Cultures made by using fragments of the blued wood taken from the center of each board showed the fungus to be dead in each case.

(b) Six blocks of pitch pine (*Pinus rigida*), each measuring 1 by 2 by 2 inches and infected with the brown-stain fungus (*Alternaria* sp.) were subjected to a so-called dry heat of 221° F. for a period of 24 hours. Cultures showed the fungus to be dead in all of the blocks at the end of the test.

(c) Disks cut transversely from the central part of two jack-pine (*Pinus banksiana*) railroad ties which had been treated with creosote and subjected during the treatment to a temperature of 178° to 188° F. for a period of 47 to 50 minutes were sent to the writer for examination. The ties were infected before treatment and showed the typical stage of rot characteristic of *Trametes pini*. Disks cut from several untreated ties and showing various stages of the same rot were also received. Cultures made from the central areas in the various disks showed the fungus to be alive in the central part of the treated disks as well as in the untreated ones. The treated ties were 7 by 8½ inches and 8 by 9¼ inches in cross section, respectively.

(d) Two sets of test pieces from the Oakridge material were subjected to 20 pounds of steam (gauge pressure, 259° F.) followed by a vacuum of 1 hour. The first set was steamed for 1½ hours and the second set for 2 hours. The results show that the 1½-hour treatment killed the organisms in the 6-inch but not in the 8-inch pieces. The 2-hour treatment killed the organisms in both sizes.

RUN 6.

A set of test pieces from the Neopit and Oakridge material was placed on stickers in an open pile in a Tiemann dry kiln. The pieces were subjected to a temperature of 110° to 116° F. at saturated atmosphere for a period of 48 hours. This set contained three 6-inch and three 8-inch test pieces of Douglas fir, the pieces of each

size being infected with *Polyporus schweinitzii*, *Trametes pini*, and *Fomes laricis*, respectively.

Upon removal from the kiln most of the pieces showed a considerable area covered with mold, which had developed during the test. The test pieces of Douglas fir of the 6 by 6 by 24 and the 8 by 8 by 24 inch sizes, freshly cut, showed green-mold growth covering the sapwood. It is apparent that the conditions were favorable to mold growth.

At the end of the test the cultural methods showed the fungi in most of the test pieces to be dead. Positive cultures developed as follows:

For the 4-inch pieces—blue stain in *Pinus strobus* and *Thuja occidentalis*, *Ganoderma tsugae* in *Tsuga canadensis*, *Trametes pini* in *Larix laricina*, *Pholiota adiposa* in *Tilia americana*, *Polyporus borealis* in *Acer saccharum*, *Polyporus amarus* in *Libocedrus decurrens*, *Polystictus hirsutus* and *P. versicolor* in *Alnus oregona*.

For the 6-inch and 8-inch pieces—*Fomes laricis* and *Polyporus schweinitzii* in *Pseudotsuga taxifolia*.

RUN 7.

Five sets of test pieces of the Neopit material were stacked in a Tiemann dry kiln. Steam was turned on gradually into the kiln until the recording instruments showed a temperature of 120° F. and a relative humidity of 100 per cent. The test was begun at this point, and this temperature and humidity were maintained.

A set of the test pieces was removed at the end of 3, 6, 9, 12, and 24 hours. Culture blocks were cut from the centers of each of the test pieces, and fragments from each block were cultured to determine the viability of the fungi.

The set of test pieces subjected to 120° F. at 100 per cent humidity for three hours upon culturing showed most of the cultures positive. In the 1-inch pieces the following were positive: Blue stain in *Pinus strobus*, brown ring-rot in *Thuja occidentalis*, *Torula ligniperda* in *Tsuga canadensis*, *Fomes pinicola* in *Tsuga canadensis*, *Fomes fomentarius* in *Betula papyrifera*, brown cubical rot in *Tsuga canadensis*, *Trametes pini* in *Pinus strobus*, and *Polyporus borealis* in *Acer saccharum*. The following were negative: Blue stain in *Thuja occidentalis*, *Trametes pini* in *Larix laricina*, brown cubical rot in *Thuja occidentalis*, *Ganoderma tsugae* in *Tsuga canadensis*, *Fomes igniarius* in *Ulmus americana*, brown cubical rot in *Pinus strobus*, *Fomes igniarius* in *Acer rubrum*, and *Pholiota adiposa* in *Tilia americana*.

The blue-stain organisms remained alive in all three sizes of test pieces, 1-inch, 2-inch, and 4-inch, during the 3-hour test in the wood of *Pinus strobus*. The blue-stain organism in the 1-inch and 2-inch test piece of *Thuja occidentalis* when cultured did not revive. The heartwood of this particular test piece was infected with a wood destroyer producing a brown crumbly or cubical rot.

In general, all the 4-inch test pieces gave positive cultures. Of the 2-inch pieces 13 gave positive and 3 negative results. The results indicate that the time and temperature factors used with this set are not practicable in killing wood-inhabiting fungi in 1-inch, 2-inch, and 4-inch stock.

The set removed from the kiln at the end of six hours upon culturing showed, in general, that the fungi were killed in all of the 1-inch

test pieces with the exception of three cases, namely, the blue-stain organism in *Pinus strobus*, the brown ring-rot in *Thuja occidentalis*, and the brown cubical rot in *Tsuga canadensis*. In this set, again, the blue-stain organism in *Pinus strobus* resisted the heat in all three sizes of test pieces, 1-inch, 2-inch, and 4-inch, and in general it stood out as a particularly heat-resistant type of infection in comparison with the rot-producing type. For the other fungi the 2-inch test pieces showed positive results in 6 cases and negative results in 10 cases, and of the 4-inch pieces 13 gave positive and 3 negative results.

The test pieces of the set subjected to the trial conditions for nine hours upon culturing showed negative results in most cases. The blue-stain organism in *Pinus strobus* was killed in the 1-inch stock. In the 2-inch stock the same organism was dead in the outer portions of the block but alive in the fragment taken from the center of the block. In the 4-inch block the organism was alive in all the fragments except those taken within a general area extending from the edge of the block to approximately 1 inch inward from the edge.

All of the 1-inch test pieces gave negative results. Of the 2-inch stock, all but two pieces gave negative results. These were *Trametes pini* in *Larix laricina* (of which only one of the five fragments gave positive results) and blue stain in *Pinus strobus*. Cultures of the 4-inch stock showed only 5 positive and 8 negative. The negative results in the 4-inch stock showed a steady increase through the 3, 6, and 9 hour tests. The conditions in this trial test were effective in sterilizing all the 1-inch stock, nearly all the 2-inch stock, and only about 61 per cent of the 4-inch stock.

The set subjected for 12 hours gave negative cultures in all but two cases. In the 2-inch and 4-inch *Pinus strobus* pieces the blue stain resisted the heat successfully.

The 24-hour test was effective in killing all the organisms in all the test pieces.

RUN 8.

Two sets of test pieces, consisting of test material from both the Neopit and Oakridge shipments, were placed in a Tiemann dry kiln for periods of six and nine hours, respectively. The temperature was maintained at 130° F. and the relative humidity at 100 per cent. Test pieces of the Oakridge shipment, 6 by 6 inches and 8 by 8 inches square, were used in this test.

At the end of the test the cultural method showed that after six hours the fungi in the centers of the 6 by 6 and 8 by 8 inch test pieces were still alive. At the end of the 9-hour test, however, all of the test pieces, including the 6-inch and 8-inch pieces, showed negative cultures.

RUN 9.

Five sets of test pieces of the Neopit material were stacked in a Tiemann dry kiln. Steam was introduced gradually into the kiln until the recording instruments showed a temperature of 140° F. and a relative humidity of 100 per cent. The test started at this point, and this temperature and humidity were maintained.

A set of test pieces was removed from the kiln at the end of 3 hours, the second set at 6 hours, the third at 9 hours, the fourth at

12 hours, and the fifth at 24 hours. As soon as the test sets were removed, 2-inch blocks were cut from the center of each piece and cultures made from these.

In the set exposed for three hours at 140° F. at saturation all the fungi were killed in the 4-inch test pieces except the blue-stain fungus (*Ceratostomella* sp.) in *Pinus strobus* and *Thuja occidentalis*, *Trametes pini* in *Pinus strobus*, *Torula ligniperda* in *Tsuga canadensis*, and the brown ring-rot of *Thuja occidentalis*. *Torula ligniperda* was alive in the 1-inch and 2-inch pieces. These results indicate that in a few cases the penetration of heat into the centers of the 4-inch test pieces was not complete at the end of three hours, at least not sufficient to kill these particular fungi. The test pieces subjected to 140° F. for 6, 9, 12, and 24 hours all gave negative results when cultured. In the three-hour trial one 2-inch test piece infected with blue stain, when cultured, gave positive results with the fragment taken from the center of the block. Fragments taken nearer the edge of the block, however, showed no revival of the fungus in the cultures.

RUN 10.

One set of test material from both the Neopit and Oakridge shipments was placed in a Tiemann dry kiln for a period of three hours at 145° F. and at saturated atmosphere.

Cultures made from the culture blocks at the end of the run showed all of the fungi to have been killed within the test pieces.

RUN 11.

Two sets of test pieces from both the Neopit and Oakridge shipments were placed in the usual manner in a Tiemann dry kiln. The pieces were subjected to a temperature of 150° F. at saturated atmosphere for a period of one hour for the first set and two hours for the second set.

Of the set subjected to the above condition for one hour the following 4-inch pieces showed positive cultures: *Polystictus hirsutus* and *Polystictus versicolor* in *Alnus oregona*, blue stain in *Thuja occidentalis* and in *Pinus strobus*, *Polyporus borealis* in *Acer saccharum*, *Trametes pini* in *Larix laricina*, *Fomes igniarius* in *Acer rubrum*, *Fomes fomentarius* in *Betula papyrifera*, and *Polyporus schweinitzii* in *Pseudotsuga taxifolia*. The remainder were negative.

Of the set subjected for two hours all of the test pieces showed upon culturing no evidence that the fungi were alive.

RUN 12.

A set of test pieces, consisting of material from both the Neopit and Oakridge shipments, was placed on stickers in an open pile in a Tiemann dry kiln. The pieces were subjected to a temperature of 170° F. at saturated atmosphere for 40 minutes. It took 20 minutes for the temperature to rise from 80° to 170° F. within the kiln after the charge was in and the doors closed. At the end of the run all the fungi were found to be dead.

BRIEF SUMMARY OF THE TEST RUNS.

Table 1, a summary of the results obtained in the 12 runs, is based upon the examination of over 1,000 test pieces and the positive or

negative results of over 8,000 culture tests. The graphs in Figure 1 are smoothed curves based upon the same data and represent graphically the time and temperature conditions required to kill the fungi under discussion.

Test runs 1 to 4, in which the ordinary commercial kiln-drying conditions were used, show conclusively that the temperatures, humidities, and periods of time were effective in killing the various fungi within the 1-inch, 2-inch, and 4-inch test pieces. These data furnish evidence which leaves little doubt concerning a phenomenon which has previously been accepted at its face value without positive proof. The additional fact that all of the samples of kiln-dried or steamed stock infected before drying and sent in by various lumber firms for examination gave negative results when cultured fur-

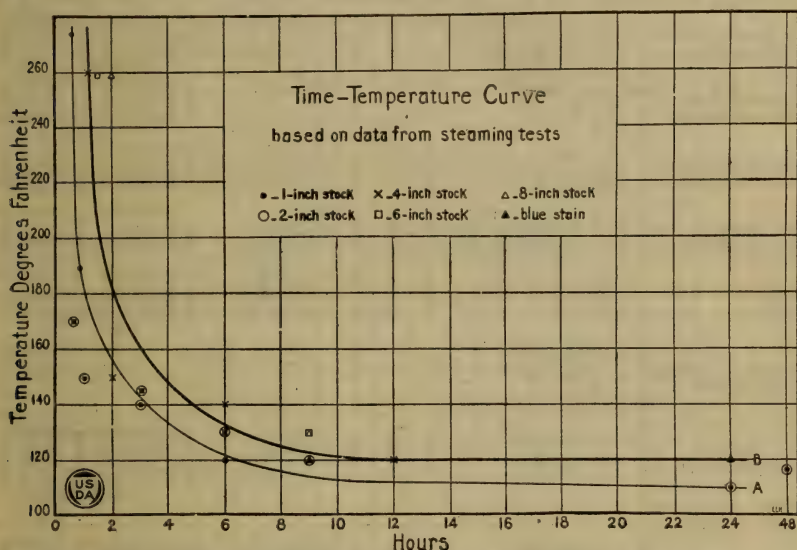


FIG. 1.—Curves showing the time-temperature relation of the data on 1-inch, 2-inch, and 4-inch test pieces from the steaming tests. Data on the 6-inch and 8-inch test pieces are included for completeness and comparison. Curve A represents roughly the time-temperature relation as expressed by the data on the 1-inch pieces. Curve B represents roughly the time and temperature limits necessary to kill certain fungi in wood up to and including 4 inches in thickness.

nishes further evidence of the sterilizing efficiency of this method of seasoning lumber.

The experimental tests, runs 5 to 12, inclusive, give somewhat more accurate data in regard to the effect of temperature on fungi in wood when acting under a constant humidity of 100 per cent. The effect of increasing the length of time during which the infected wood is subjected to a constant temperature and humidity and the relatively greater resistance of the larger sized test pieces to the penetration of heat are both clearly shown in runs numbered 6, 7, and 11 in Table 1 and in Figure 1. In run No. 7 the temperature used, 120° F., was sufficiently low to require a period of 24 hours before all the fungi were killed in the test pieces. This gave a fairly good comparison of the relative resistance to heat of the various fungi within the wood.

TABLE 1.—Effect of various heat treatments, etc.—Continued.

Fungus or rot and host.	Size of test piece (inches).	Run No.											
		1	2	3	4	6	7			8	9		
		120° to 135° F., 16 days.	95° to 160° F., 40 days.	143° to 168° F., 12 days.	135° to 180° F., 18 days.	110° to 116° F., 48 hours.	120 F.			130° F.	140° F.		
		3 hours.	6 hours.	9 hours.	12 hours.	24 hours.	6 hours.	9 hours.	24 hours.	6 hours.	9 hours.	12 hours.	24 hours.
Polystictus hirsutus in <i>Picea canadensis</i>	2 by 10 by 48	D	D	D	D	D	D	D	D	D	D	D	D
Polystictus hirsutus and <i>P. versicolor</i> in <i>Alnus oregana</i>	1 by 4 by 24 2 by 4 by 24 4 by 4 by 24	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D
<i>Torula ligniperda</i> in <i>Tsuga canadensis</i>	1 by 4 by 24 2 by 4 by 24 4 by 4 by 24	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D
<i>Trametes pini</i> in <i>Picea canadensis</i>	2 by 10 by 48	D	D	D	D	D	D	D	D	D	D	D	D
<i>Trametes pini</i> in <i>Larix laricina</i>	1 by 4 by 24 2 by 4 by 24 4 by 4 by 24	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D
<i>Trametes pini</i> in <i>Pinus strobus</i>	1 by 4 by 24 2 by 4 by 24 4 by 4 by 24	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D
<i>Trametes pini</i> in <i>Pseudotsuga taxifolia</i>	6 by 6 by 24 8 by 8 by 24	D D	D D	D D	D D	D D	D D	D D	D D	D D	D D	D D	D D
Brown cubical rot in <i>Pinus strobus</i>	1 by 4 by 24 2 by 4 by 24 4 by 4 by 24	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D
Brown cubical rot in <i>Thuja occidentalis</i>	1 by 4 by 24 2 by 4 by 24 4 by 4 by 24	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D
Brown cubical rot in <i>Tsuga canadensis</i>	1 by 4 by 24 2 by 4 by 24 4 by 4 by 24	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D
Brown ring-rot in <i>Thuja occidentalis</i>	1 by 4 by 24 2 by 4 by 24 4 by 4 by 24	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D	D D D

Minor preliminary tests were included under run No. 5, a, b, c, and d. The test given in 5, a, indicates that the steaming process, where pressure is used for short periods of time, is effective in killing the blue-stain fungus, at least in 1-inch stock. The sterilizing effect of the ordinary method of oven drying blocks of wood is given under 5, b, and the data on the failure of a particular preservative treatment in sterilizing the center of 8-inch ties infected with a heart rot is given under 5, c. It was noted that in the areas where the creosote had penetrated the infected wood the fungus no longer revived when cultured, but revived in cultures made by using fragments taken from the untreated portions near the center of the ties. From the face of the tie to a point 2 inches in from the face no positive cultures were obtained from the infected area; beyond this point and toward the center, positive cultures were obtained. The heat apparently was effective in sterilizing to a depth of 2 inches. Under 5, d, it was found that a steaming treatment of two

hours followed by a vacuum of one hour was necessary in order to sterilize to the center the 8-inch test pieces.

AIR-SEASONING EXPERIMENTS.

In the first air-seasoning experiments infected planks 2 by 10 inches and 4 feet long cut from spruce (*Picea canadensis*) pulp logs were used. These planks contained typical and incipient stages of the decays produced by *Lenzites sepiaria*, *Trametes carnea*, *Polyporus anceps*, *Trametes pini*, *Polystictus abietinus*, and *Fomes pinicola*.

On July 28, 1920, 21 planks representative of the above material were stacked in the yard of the Forest Products Laboratory. The open method of stacking was used, and the layers of planks were separated by half-inch stickers. Adjacent to this pile another pile containing 33 planks was constructed. In this case the planks were closely piled one on top of the other. A third set of 39 planks of the same material was stacked open piled, while a fourth set of 28 planks was stacked close piled in a well-inclosed shed.

On June 11, 1921, records were taken concerning the number and species of fungous sporophores developed upon the planks since the piles were constructed. The open pile in the yard showed a total of 41 sporophores, of which 35 were *Lenzites sepiaria* and 6 were *Trametes carnea*. There were 23 sporophores on the planks in the close-piled set, and of these 13 were of *Lenzites sepiaria*, 2 were *Trametes carnea*, 6 *Polystictus abietinus*, and 2 *Polyporus anceps*. Most of these sporophores were of small size, but capable of producing spores. Many of the smaller of these dried out perceptibly during the warm, dry weather, but revived again during the prolonged rainy periods. Most of the sporophores appeared during the spring months. It is interesting that the largest number of sporophores were found upon the open pile and that of these over 85 per cent were of *Lenzites sepiaria*, a fungus which thrives under comparatively dry conditions. In the closed pile only 56 per cent of the total sporophores were of *Lenzites sepiaria*, and three other species were represented, in contrast to two species in the open pile.

Cultures made from test blocks cut from the planks stored in the two piles in the shed showed that the fungi within the wood were still alive, although there were no indications that the decays had progressed within the planks. No sporophores had developed on any of these planks.

On April 25, 1922, notes were again taken on the sporophore crop appearing upon the planks stacked in the yard. On the planks in the open pile a total of 61 sporophores were noted. Some of these were resupinate in character, and a few were buttons, or rudimentary fruit bodies. Of this total, 50 (or about 82 per cent) were *Lenzites sepiaria*, 7 *Trametes carnea*, 2 *Polyporus anceps*, and 2 *Stereum* sp. On the closed pile were found 69 sporophores with about 10 buttons. Of this total, 42 (or about 61 per cent) were *Lenzites sepiaria*, 13 were *Trametes carnea* with 10 buttons, 7 were *Polyporus anceps*, 5 *Polystictus abietinus*, and 2 *P. versicolor*.

A comparison of the closed pile with the open pile indicates that the closed pile is more favorable to sporophore production and pre-

sumably to decay activity. The records taken on April 25, 1922, show an additional genus and two additional species over those taken on June 11, 1921.

As an additional control, a closed pile was constructed in the yard on July 28, 1920. This was made of the infected planks removed from the kiln (run 2) which showed by culturing that the fungi in the wood had been killed. This pile was subject to the same environment as the other two piles in the yard. No sporophores developed upon these planks.

REVIVAL OF FUNGI IN WOOD AFTER AIR DRYING.

Green infected lumber piled for air seasoning or for storage contains the live organisms which cause rot and sap-stain. These organisms can remain inactive in wood during periods when the lumber is kept dry, but can revive and continue their development and therefore extend the decay or stain in the presence of favorable moisture and temperature conditions. The approximate length of time during which wood-destroying and sap-stain organisms can remain alive in wood under continued air-dry conditions has been determined for certain fungi by means of the method here outlined.

Blocks of wood infected with known fungi were stored on shelves in the dry air of the laboratory, in which the temperature range was between 64° and 74° F. Cultures were made at intervals, usually six months apart, using fragments of the infected wood. Positive cultures indicated the revival of the fungus in each case. In order to determine whether the new growth developing from the infected fragment grew from the old hyphae in the wood and not from spores, either secondary or primary, or from young hyphae of a possible recent infection of the wood, cover-glass cultures were made. Thin sections of the infected wood were cut, washed in distilled water, and under sterile conditions placed under a cover glass on a thin layer of malt agar on a glass slide. Here the growths of the hyphae were observed under the microscope. In all cases the new growth was traced to the "sprouting" of the old hyphae in the wood (fig. 2). This was observed for the following fungi: *Trametes carnea*, *T. pini*, *Polyporus anceps*, *Trametes serialis*, *Fomes pinicola*, and *Ceratostomella* sp.

The results given in Table 2 show the cultures completed up to January, 1923.

The blue-stain fungus in one case was estimated to have remained more or less dormant for a period of seven years. *Trametes serialis* (?) in a Douglas fir timber was found to revive after use of the

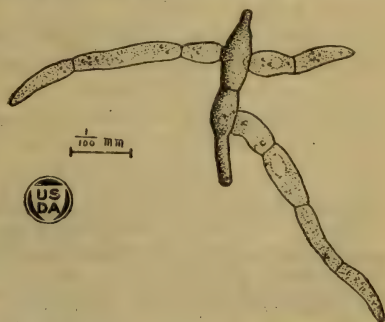


FIG. 2.—An old fungous thread (hypha) of the blue-stain fungus which has revived and produced three new growing branches. The hyphae in the wood (*Pinus strobus*) were air dry and dormant for some time, but revived when sufficient moisture was supplied. Enlarged about 800 times.

timber in a building for 4½ years and subsequent storage in the laboratory for over 7 years. Complete records on *Polyporus amarus* in *Libocedrus decurrens* showed that the fungus remained alive up to about eight months. Cultures made from the infected wood one month and eight months later showed no growth. Cultures of this fungus develop slowly when fragments are taken from material not freshly cut from the tree or log. In some cases 20 to 25 days elapsed before the growth appeared on the agar slants or the inoculum.

The fungi recorded in the "Live" column are still under observation, and in no way can these results be taken as the limits of vitality of the different fungi. The figures in the "Dead" column indicate only that the fungus did not revive when cultured. Just when the ability to revive was lost has not been determined.

TABLE 2.—Length of time certain fungi remain alive but inactive in wood stored in the air-dry conditions of a room.

[Date when last cultured, January, 1923.]

Fungus.	Host.	Length of time in storage, air-dry condition.			
		Live.		Dead.	
		Years.	Months.	Years.	Months.
Ceratostomella sp.	Pinus ponderosa	3	0		
Do.	Pinus strobus	3	0		
Do.	Southern yellow pine	7	0		
Echinodontium tinctorium	Tsuga heterophylla	5	7		
Fomes annosus	do.			5	0
Fomes applanatus	Populus trichocarpa	1	5	2	4
Fomes igniarius	Acer rubrum	1	5		
Do.	Populus tremuloides			10	0
Fomes laricis	Pseudotsuga taxifolia	1	0		
Fomes pinicola	Tsuga heterophylla	1	4		
Trametes carnea	Picea canadensis	2	9		
Do.	do.	2	7		
Ganoderma tsugae	Tsuga canadensis		6	1	3
Lentinus lepideus	Southern yellow pine			2	4
Lenzites sepiaria	do.	2	7		
Do.	Picea canadensis	2	9		
Do.	do.	6	2		
Do.	do.	6	3		
Pholiota adiposa	Tilia americana	1	5		
Do.	Abies grandis			6	3
Pholiota sp.	do.	6	0		
Polyporus adustus	Nyssa sylvatica	1	8		
Polyporus amarus	Libocedrus decurrens		7		8
Polyporus anceps	Picea canadensis	2	7		
Do.	Pinus ponderosa	3	5		
Polyporus schweinitzii	Pseudotsuga taxifolia	1	0		
Polyporus stipticus	Pinus ponderosa	2	1		
Polyporus sulphureus	Quercus sp.	1	4		
Do.	Quercus rubra			10	0
Polystictus versicolor	Alnus oregona	2	6		
Polystictus hirsutus	do.	2	6		
Trametes pini	Larix laricina	1	5		
Do.	Picea canadensis	2	3		
Do.	Pinus monticola			5	0
Do.	Tsuga heterophylla			7	2
Trametes serialis (?)	Pseudotsuga taxifolia	7	5		
Fusarium negundi (red stain)	Acer negundo	1	6		
Brown cubical rot	Thuja plicata	1	6		
Do.	Thuja occidentalis	1	6		
Brown pocket rot	Sequoia sempervirens	5	0		

In general, the results at this time show that certain fungi in wood can remain alive though dormant for long periods under the air-dry conditions of a room and are capable of reviving and producing new growth when sufficient moisture is added.

REVIEW OF THE RESULTS.

Sterilization by heat is a well-known process and has its examples in many everyday activities. The canning of fruit is probably the best-known example, and it is but a short step from this to the sterilization of wood—a very similar process. The protection of wood against future infection is not accomplished by sterilization alone. Proper care following sterilization is absolutely essential, and in the case of lumber proper storage to insure dryness is the process by which reinfection is prevented. This fact has prompted the inclusion of the air-seasoning data for correlation with the results of the heat experiments. It will be of interest to note here that wood when properly kiln dried is equal in strength to air-dried wood when moisture contents are carefully considered (10).

A brief consideration of the factors affecting the penetration of heat into sound and infected wood may not be out of place here. Very little has been published on this subject. Hunt (3) in a series of experiments obtained data on the rate of heat penetration into sound wood of various sizes and species. Using sawed ties of maple, red oak, loblolly pine, and hemlock 6 by 8 inches by $8\frac{1}{2}$ feet he found that under the conditions of the experiments no appreciable difference in rate of increase of temperature due to difference in species could be determined. He also observed that the interior of the ties never quite gained the temperature of the heating medium and that seasoned ties heated more rapidly than green ties. In the treatment with steam at 20 pounds pressure the time required for the interior to reach 212° F. varied from $2\frac{3}{4}$ to 5 hours, averaging 4 hours and 20 minutes. With steam treatment at atmospheric pressure the ultimate maximum temperatures within the ties varied from 2 to 17 degrees F. less than the temperatures of the surrounding medium. With steam at 20 pounds pressure the variation was from 2 to 21 degrees F.

In regard to the experimental data in this bulletin, the effect of heat upon the fungi in the wood was observed to vary with the size of test pieces and the relative porosity of the wood as expressed by the stage of decay. In many cases negative cultures were obtained from portions of the culture block, showing a typical stage of decay which was obviously more porous than the near-by areas of incipient decay. In other cases the blue-stain fungus present in the sapwood of the piece was killed in blocks showing a brown cubical or brown ring-rot in the adjoining heartwood, and it remained alive in blocks of similar size containing only incipient stages of decay in the adjoining heartwood. The data on the steaming experiments when plotted on coordinate paper show in general a definite relationship between time and temperature. This is clearly evident in the curves shown in Figure 1. Curve A is drawn through points representing data on the 1-inch test pieces. Curve B is more or less theoretical and represents roughly the time and temperature limits necessary to kill certain fungi in wood up to and including 4 inches in thickness. The point in Figure 2 showing death of the fungi in 4-inch stock subjected to 140° F. for six hours is considerably outside the curve and theoretically should coincide with the curve near the $4\frac{1}{2}$ -hour point. It is evident that the fungi in this case were killed

before the six-hour limit was reached, as another test (run 10) shows that the fungi were dead in the 4-inch stock subjected to 145° F. for three hours. For completeness, the points representing the data on 6-inch and 8-inch stock, as well as the high values obtained for the blue-stain organisms, are given.

In the steaming experiments a saturated atmosphere was used in order to avoid as much as possible variations in heat penetration which might be due to variations in moisture content of the test pieces, since the experiments of Hunt (3) have shown that seasoned wood heats more quickly than green wood. The data from the steaming experiments are thus directly applicable to the preliminary steaming now generally recommended for various commercial kiln runs. This preliminary steaming consists of subjecting the wood at the beginning of the run to live steam (160° to 185° F.) for half an hour to three hours. By glancing at the temperatures and periods of time given in Table 1 and comparing these with the temperatures and periods of time given for the hardwood and softwood drying schedules by the Forest Products Laboratory (1, 4, 11) it will be seen that with very few, if any, exceptions the heat and periods of duration of each schedule are sufficient to sterilize wood (for the fungi of these experiments) up to and including 4 by 4 inches in cross section. In the drying schedules for hardwoods the lowest temperature used is 115° F. for an average period of 56 days and the highest temperature 170° F. for 3 to 4 days. The lowest and highest temperatures used in the various schedules for drying softwoods are 135° and 200° F., respectively. The lowest temperature used in the steaming experiments was 110° F. for 48 hours; the highest was 170° for 40 minutes at atmospheric pressure and 274° at 30 pounds gauge pressure. The first is successful in sterilizing wood up to but not including all the test pieces of a thickness of 4 inches; the last has been tested for 1-inch stock only.

From the experimental data obtained in this study the following results are shown for the hosts and fungi studied:

(1) A long list of fungi consisting of both wood-destroying and sap-stain organisms in a variety of hosts can effectively be arrested in their development through sterilization by heat.

(2) The blue-stain fungus is apparently the most resistant of those tested.

(3) The stage of decay of certain fungi may affect the rate of heat penetration within infected wood.

(4) The temperature of commercial kiln runs, excepting temperatures below 120° F., are effective in sterilizing infected wood up to and including 4 by 4 inches square. Pieces 6 by 6 inches and 8 by 8 inches square were sterilized by treatment at 130° F. for nine hours at saturated atmosphere and by steam-pressure treatment.

(5) Infected wood piled in the yard at Madison, Wis., in both open and closed piles and unprotected against rain, will continue to develop decay and in many cases fungous fruiting bodies.

(6) Similar material piled in dry sheds protected from moisture showed no outward signs of fungous activity, but the fungi remained alive though inactive. Uninfected wood in the same shed remained sound.

(7) Certain fungi dormant or inactive within air-dry wood for long periods of time are capable of reviving and continuing their development upon the return of favorable moisture conditions.

One investigator (12) has shown that a fairly high moisture content of the wood, about 25 per cent, is needed before spores of *Lenzites sepiaria* will germinate readily upon the surface and subsequently cause infection.

Münch (5) has shown that for a blue-stain fungus (*Ceratostomella coerulea* Münch) in the sapwood of Scotch pine (*Pinus sylvestris* L.) the optimum moisture content of the wood lies between 33 and 74 per cent, based upon the oven-dry weight. Above and below these limits the activity of the fungus decreases, and at 143 per cent no growth was noted. At 28 per cent little growth was evident. The same writer also states that the moisture content favorable for the blue-stain fungus agrees in general with the moisture requirements of certain wood-destroying fungi.

Snell (7) has reported on one series of experiments in which he used *Lenzites sepiaria*, *L. trabea*, *Trametes serialis*, *Fomes roseus*, and *Lentinus lepideus* in loblolly-pine sapwood (*Pinus taeda* L.) and Sitka spruce (*Picea sitchensis*), presumably heartwood. He found that the results upon loblolly-pine sapwood agreed very closely with those of Münch on Scotch pine. Very little decay was recorded when the quantity of water in the wood was below the fiber saturation point, a moisture content of 25 per cent in terms of the oven-dry weight of the wood. With the increase in moisture content the decay increased, and the greatest development of decay occurred between 33 and 42 per cent (or 49 and 72 per cent based on the oven-dry weight). At 50 per cent there was little decay, and no decay was noted at 60 per cent (150 per cent, oven dry). With spruce the decay began a little below the fiber saturation point, and the greatest development was noted between 30 and 57 per cent (43 and 133 per cent, oven dry). At 67 per cent (203 per cent, oven dry) neither penetration by the hyphæ nor decay was noted.

These experiments indicate that a moisture content considerably above the fiber saturation point of wood is required for the optimum development of at least certain fungi within wood. How long this optimum condition must be maintained to produce decay in stored lumber is not known, nor are there any figures to show whether alternate wetting to the fiber-saturation point and above and drying to 17 per cent and lower is favorable or unfavorable to fungous development. In regions where the rainfall is heavy and continuous over long periods the unprotected and poorly protected lumber would unquestionably develop wood-inhabiting fungi. It is doubtful whether lumber properly dried and carefully stored under cover would absorb sufficient moisture from a humid atmosphere to sustain continuous fungous growth within the wood.

With these facts as a basis, it seems reasonable to suppose that wood properly kiln dried will be sterilized and that if it is then properly stored in dry well-ventilated piles protected from all moisture (except the moisture absorbed from the air) the stock will remain bright and sound.

SUMMARY.

The need is shown for some practical method or methods of sterilizing wood against the fungi inhabiting it, and the wide application of such methods to the wood producing and consuming industries is indicated.

The tests carried out show that a long list of wood-inhabiting fungi in a variety of woods can effectively be arrested in their development through sterilization by heat.

Of the various fungi tested the blue-stain fungi appear to be the most resistant to heat. No great differences in resistance were noted among the various rot-producing fungi tested.

Commercial kiln conditions and steaming processes coming within the effective limits of temperature and time as determined by the tests are effective in sterilizing infected wood up to and including pieces 4 by 4 inches square. Pieces 6 by 6 and 8 by 8 inches square were sterilized when subjected to 130° F. for a period of nine hours. Sterilization was also effected by steam-pressure treatments.

Methods of piling and storage are important factors in protecting wood against deterioration due to fungi.

Certain fungi continue to develop in wood as long as favorable conditions are present, and they will revive and continue development after long periods of drying.

From the data obtained it is assumed that wood that is properly kiln dried will be sterilized and that with proper storage it will remain bright and sound.

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CONTROL OF DECAY IN PULP AND PULP WOOD

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IMPORTANCE OF DECAY PROBLEM IN PULP INDUSTRY

The pulping of wood for the production of paper and various fiber products is one of the major industries of the United States. It is largely concentrated in the northern region beginning with Minnesota and extending eastward. The six leading pulp-producing States

are Maine, New York, Wisconsin, Pennsylvania, New Hampshire, and Minnesota. Thirty per cent of the newsprint-manufacturing industry is in New England, nearly 50 per cent in New York, and 15 per cent in the Lake States.

Statistics (20)¹ recently published will give some idea of the magnitude of the operations. During 1920, 253 establishments reported the use of 6,114,072 cords of wood valued at \$116,495,720, with an average cost per cord of \$19.05 f. o. b. mill. This material produced 3,821,704 tons of pulp, of which 1,583,914 tons were mechanical, 1,585,834 sulphite, 463,305 soda, and 188,651 sulphate pulp. The pulp wood consumption in 1920 showed an increase of 16 per cent over 1918. This demand was met in part by the importation of nearly a million and a quarter cords of spruce and poplar.

An abnormal demand for pulp developed in 1919, because of the world shortage following the war, and this continued until the latter part of October, 1920. Wood and pulp increased correspondingly in value, and losses from decay and mold, assuming greater monetary significance, came sharply to the attention of operators and evoked many requests for assistance in controlling or reducing the losses. The Federal Government did not have funds immediately available to finance the necessary investigative work, and a group of 33 interested mills subscribed to a fund which enabled the Forest Products Laboratory to employ two pathologists (who were detailed from the Bureau of Plant Industry) and two chemists to study the problem.

A preliminary survey of the situation was made at some twenty of the cooperating mills in Wisconsin, Minnesota, New York, and Pennsylvania. At these mills the problems were discussed with the operators, and inspections were made of wood and pulp storage facilities and methods. The survey disclosed heavy losses at most mills, particularly in the storage of wood, and past losses of considerable extent in the storage of ground wood pulp. One mill had lost more than \$100,000 on ground wood stored inside for a comparatively short time. At another mill a loss exceeding \$10,000 occurred in a 7,500-ton lot of hydraulic-pressed ground wood from Canadian spruce stored for two or three years. This was in an outside pile about 20 feet high, unprotected above but placed on a plank foundation. The company reported this pulp about 72 per cent air dry (65 per cent oven dry). There were also several instances in which ground wood, infected at one plant and shipped to another, had rotted very rapidly after arrival. Such direct cancellations of unsalable pulp from the books create a very distinct impression of loss; but there is a much greater loss, in the aggregate, from deterioration which is not sufficiently marked to cause rejection, though sufficient to reduce the market value of the product. All these elements the present investigators have tried to take into account.

Little attention has been paid in the past to losses from pulp wood rotting in the yard or in the woods. Rot has been recognized only after it became sufficiently advanced to affect the strength of the pulp, thus necessitating a larger proportion of sulphite to produce newsprint. In only one instance was wood found which was so far rotted as to be considered unfit for use. This had been in storage about four years. Many mills have been operating for years on

¹ Numbers in italics in parentheses refer to literature listed in "Bibliography," p. 80.

wood with a considerable admixture of decayed material, so that a "normal" yield with them is not the normal for sound wood, and losses figured on that basis would be underestimated. In fact, definite data on comparative losses in pulping sound and infected woods, either by mechanical or chemical processes, were lacking. Decay in the wood yard was considered rather an "act of Providence" than a direct result of storage conditions highly favorable to the growth of wood-destroying fungi.

Since the improvement of storage conditions in the wood yard and the working out of a method for the preservation of pulp by the addition of antiseptics appeared to be the two problems of greatest significance, it was decided to direct the investigative work especially along these lines.

The present study, however, combines investigations on all phases of the deterioration problem. Rarely is the opportunity offered, as in this case, to correlate mill tests and commercial practice with pathological and chemical laboratory investigations of the same material. It is the ideal way to conduct a commercial study.

The investigations cover the cause of decay in wood and wood pulp and the conditions which favor it. This information, when adapted to commercial practice, will go far toward reducing deterioration in these products.

The pulping characteristics of decayed wood have been investigated with special reference to the losses actually occurring under present commercial methods of storage. Pulping value depends to a large degree upon the nature of the process used. With decayed wood as raw material, mechanical pulp is characterized by low yields, dark color, and to some extent low strength; soda pulp by high consumption of chemicals, low yields; and decidedly low strength. Sulphite pulp, on the other hand, unless made from wood badly deteriorated, has characteristics not greatly different from those of pulp made from sound wood. The yield, when expressed in terms of weight of both wood and sulphite pulp, is not materially lower, although the pulp is slightly darker and becomes somewhat brittle when beaten. When the wood has become badly decayed, however, the deterioration is reflected more positively in the characteristics of the pulp.

In order to determine the relation between decay and pulping value, it was necessary to study the subject from both a chemical and a pathological angle. The investigations show that the changes in the wood substance leading to poor quality and quantity of pulp are due to a physical breaking down of the fibers accompanied by chemical changes in which even the cellulose is finally changed from a stable form to an unstable condition more soluble both in water and cooking liquor.

By the application of known principles of sanitation and rotation it is possible to reduce materially the losses which result from decay during the handling and storage of pulp wood. It is not feasible, however, to eliminate entirely from the mill all the pulp wood which has become decayed. The rapidity with which the pulp wood supply in the United States is vanishing makes it imperative that even the decayed wood be used wherever economically possible. Many trees are attacked by fungi and begin to rot while they are still on the stump, especially those which have reached maturity or those which have suffered from attack of insects, from suppression, or from

mechanical injury. The extensive ravages of the budworm in the spruce and balsam forests, for example, have resulted in the death of more than 40 per cent of these important pulp-wood species in the areas affected. Trees weakened or killed by this pest quickly show signs of rot.

Investigations thus become necessary to determine to what extent deterioration can proceed before the wood loses its economic value for pulping. Such investigations are under way at the Forest Products Laboratory, and it is hoped that the results will lead to better methods of selecting the wood, to the end that the value of partially decayed material will be fully realized.

In connection with the control of decay and molding in pulp stored commercially, much attention has been devoted to the use of antiseptics introduced into the pulp to prevent the development of fungous growth. This was found necessary since no other remedy seemed at all feasible. During the progress of the investigation a brief report of the behavior of some of the most effective antiseptics and of the method of their application was distributed to the industry through the courtesy of the American Paper and Pulp Association.

As there are many fungi concerned in the deterioration of both pulp wood and stored pulp, it was necessary to determine which of these were the more detrimental. For this reason a large number of fungi were studied individually in pure culture in order to determine their action on wood fiber, and the resultant infected pulps were examined both chemically and physically with the same object in view. This investigation will be continued and expanded to include other fungi which produce rots of distinctive types prevalent in pulp-wood species.

DECAY OF WOOD

Decay in wood is produced by fungi. These fungi are plants, differing from the ordinary green plants merely in their form, lack of green coloring matter, and methods of nutrition. Ordinary plants get their nutriment from the soil and air; wood-destroying fungi utilize wood substance for this purpose.

Many fungi are wood inhabiting, but not all are wood destroying. In studying the effect of fungi on pulpwood and pulp it is necessary to discriminate between two broad groups of fungi—namely, molds and wood destroyers. Molds are abundant on pulp, particularly ground wood, but play so little part in the actual disintegration of wood fiber that their effect on its strength may be ignored. The active wood-destroying organisms are for the most part hymenomycetes, or fungi comparatively high in the scale of development. These fungi feed actively on the wood substance.

In the life cycle of wood-inhabiting fungi two essential stages of development are recognized: (1) The mycelial, or vegetative stage, during which the fine, cotton-like branched threads (the mycelium) of the fungus penetrate the wood and also develop on the surface if the surrounding air be moist; and (2) the fruiting stage, during which spores are produced for the further propagation of the fungus.

The mycelium (Pl. I, fig. 1) is the absorbing system of the fungus, and in function is comparable to the root system of ordinary green plants. In the case of molds, the mycelium enters chiefly the ducts or medullary rays of the wood, where it feeds on the starches, sugars,

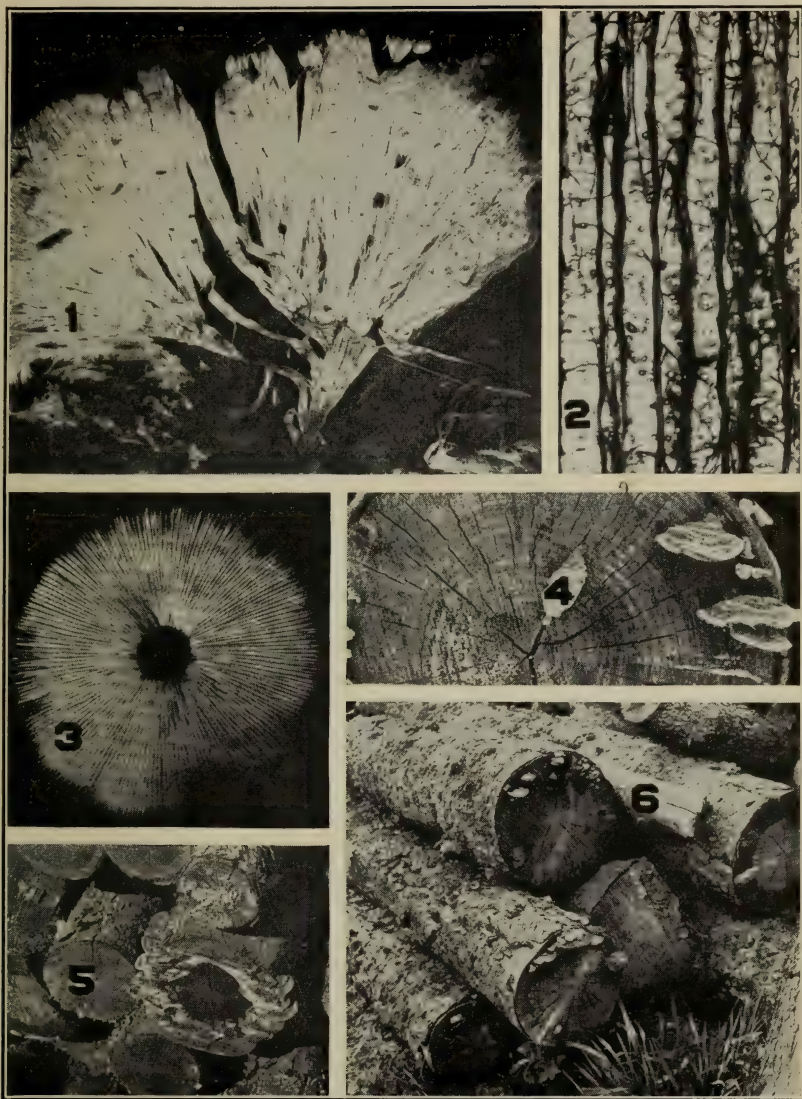


FIG. 1.—Mycelium of a wood-destrorying fungus on ground wood after six months' storage in a mill basement

FIG. 2.—Mycelium of *Trametes pini* in southern yellow pine. The small black lines are the fungous threads. The heavy lines are the walls of the wood fibers. Note the numerous small holes where the threads have perforated the walls of the fibers

FIG. 3.—Spore print of a mushroom, *Lepiota naucina*, obtained by placing the cap, gills down, on a piece of black paper. The spores were cast by the billion. (After Atkinson)

FIG. 4.—Fruit bodies of *Polystictus hirsutus* on the end of an aspen pulp log. This fungus is limited to hardwoods

FIG. 5.—Fruit bodies of *Fomes roseus* (the larger) and *Polystictus abietinus* on the end of spruce pulp logs in the pile of three-year wood shown in Pl. VI, fig. 3. These two fungi are the most prevalent species on conifers

FIG. 6.—Fruit bodies of *Lenzites sepiaria* on spruce pulp logs. This fungus is confined almost entirely to conifers and develops readily on the drier exposed timbers

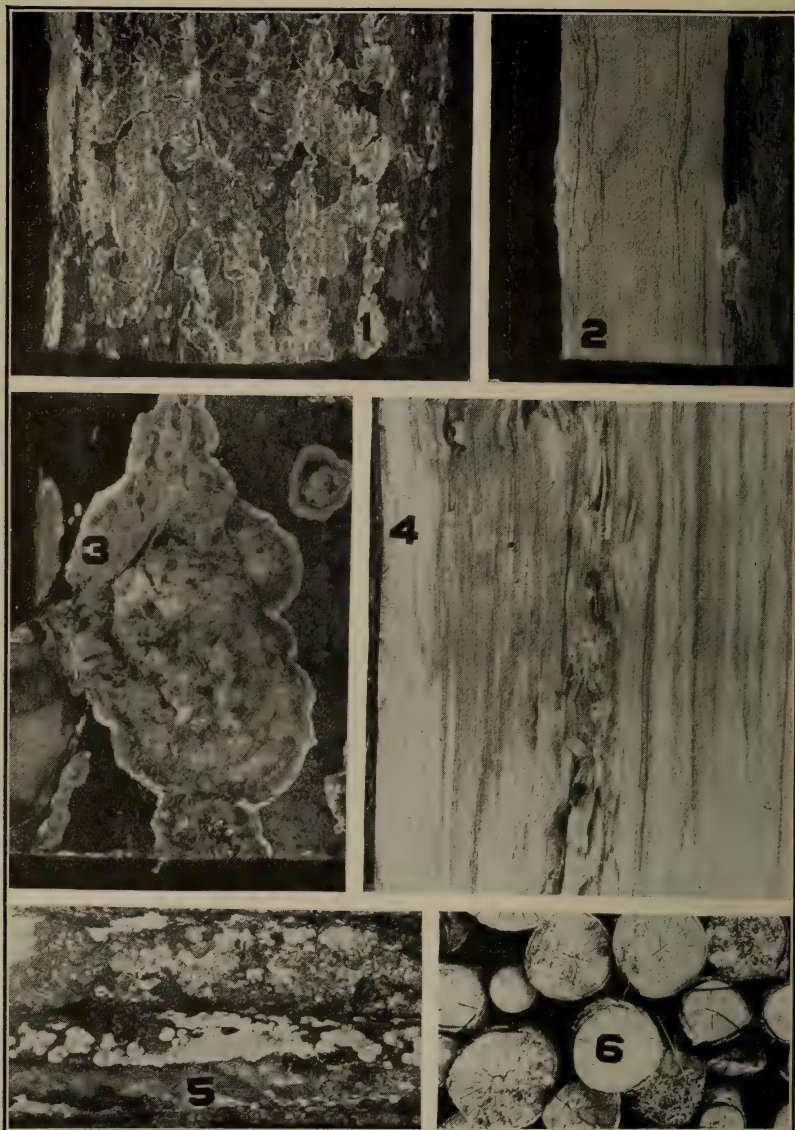


FIG. 1.—Encrusting fruit bodies of *Polystictus abietinus* on a hemlock pulp log. This fungus is

very abundant on coniferous wood. The pore surface is violet when fresh

FIG. 2.—Longitudinal section of log shown in fig. 1. Note the minute pockets, primarily in the

sapwood, which are characteristic marks of this fungus

FIG. 3.—Fruit bodies of *Polyporus adustus* on aspen pulp wood. The pore surface is smoky brown to smoky black. This fungus attacks hardwood pulp logs, particularly aspen, very

vigorously.

FIG. 4.—Rot in log shown in fig. 3

FIG. 5.—Fruit bodies of *Stereum sanguinolentum* on spruce pulp log. At the ends of the log the fungus also forms small brackets. The spore-bearing surface "bleeds" if scratched when

fresh. The fungus attacks mainly the sapwood of conifers and is not a severe wood destroyer

FIG. 6.—Fruit bodies of *Stereum purpureum* on aspen pulp logs. The spore-bearing surface is purplish when fresh. This fungus is particularly prevalent on aspen and apparently produces considerable decay. The wood shown had been in the yard less than a year

and other easily digested organic compounds. It may also pass through the pits in the walls of the wood fibers, but rarely bores through the solid wood substance. For this reason, molds on timber do not affect its pulping quality. The mycelium of wood destroyers, though often quite similar in appearance to that of molds, can usually be distinguished by its disintegrating action on the wood fiber. (See Pl. I, fig. 2.)

In order to propagate itself successfully, every fungus must have a fruiting or spore-bearing stage. The spores of molds are usually borne directly on somewhat specialized superficial mycelium. The spores of wood-destroying fungi are, with the exception of secondary ones produced in certain cases, borne on or within definite fruit bodies (conchs, brackets, toadstools, mushrooms, leathery incrustations, etc.), whose shape, color, and texture are quite characteristic for the different fungi. (See Pls. I, II, and XVIII.)

Spores, in function, are entirely comparable to seeds. They are microscopic in size and extremely light, and appear (Pl. I, fig. 3) as a very fine powder, which is very often white, though the color varies for different fungi. Frequently the spores from a single fruit body will number into the billions, most of them being capable of producing a new plant. With so many spores blowing about in the air and settling on new timber, it is evident that the chances for infection are very great, provided the conditions for germination are favorable. The most active period for the casting of spores from the fruit bodies is during moist weather, which in turn is most favorable for germination and subsequent infection.

CONDITIONS NECESSARY FOR GROWTH OF FUNGI

The conditions necessary for the growth of fungi are (1) the presence of an adequate food supply, (2) sufficient moisture, (3) at least a small amount of air, and (4) a suitable temperature.

Food is supplied by the wood tissues, and the more easily these tissues are attacked the more readily will the wood disintegrate. The sapwood of practically all species of American timber is non-resistant to fungous attack, and the heartwood of most of the principal pulp-wood species is hardly more durable than the sapwood.

Where there is a suitable food supply for the fungi, moisture is, without doubt, the most important factor in decay. The different fungi, however, appear to vary somewhat as to their water requirements. For infection and the early stages of decay a comparatively high moisture content of the wood and the surrounding air is highly favorable for all fungi. In discussing the effect of atmospheric moisture on the germination of spores of *Lenzites sepiaria* on shavings of shortleaf pine sapwood, Zeller (28) shows that 85 to 100 per cent of them germinate only at the high relative humidities of 98 to 99 per cent. This writer considers that fiber saturation² of the wood is attained at 95 to 96 per cent relative humidity, and concludes that even at this point germination is considerably retarded, and that below fiber saturation it falls off with extreme rapidity. A slight

² Green wood usually contains water within the cell walls and "free" water in the pores. In drying, the water in the pores is the first to be evaporated. The fiber saturation point is that point at which no water exists in the pores of the timber, but at which the cell walls are still saturated with moisture. The fiber saturation point varies with the species. The ordinary proportion of moisture, based on the dry weight of the wood, at the fiber saturation point is from 20 to 30 per cent.

film of water on the wood surfaces, he believes, is highly favorable to germination. Just what moisture content of wood is most favorable to decay after infection has once taken place is not known. Nor is it known what moisture is necessary for infection of sound wood from an infected stick lying in contact with it, so that the mycelium may grow from the one to the other. The study of this phase of the problem is complicated by the fact that moisture may possibly be added to the wood by direct secretion from the mycelium and by the breaking down of the wood substance itself, in which process water is one of the products formed. Decay may therefore appear in certain cases, to take place somewhat below fiber saturation.

A certain amount of air in the wood is absolutely necessary for the occurrence of decay. The fungi require it in their growth. When the wood is saturated, the air in the wood cells is displaced by water, and fungous growth and decay are impossible.

The fungi which decay pulpwood generally grow best at temperatures between 75 and 95° F. All will grow at much lower temperatures, but much more slowly. The most severe winter conditions do not kill them. They merely cease growing and remain dormant. On the other hand, a rise of temperature of but a few degrees above the optimum has a greater retarding influence on growth than a corresponding reduction. The conditions of moisture and temperature under which fungi thrive are such that in most pulp-wood regions they will find a favorable environment during the greater part of the year.

FUNGI THAT DECAY STORED PULP WOOD

The fungi which have been found causing extensive decay in stored pulp wood in the regions investigated are: *Polystictus hirsutus* (Pl. I, fig. 4); *Polystictus versicolor*, *Polyporus adustus* (Pl. II, figs. 3 and 4); *Stereum purpureum* (Pl. II, fig. 6); *Fomes roseus* (Pl. I, fig. 5); *Lenzites sepiaria* (Pl. I, fig. 6); *Polystictus abietinus* (Pl. II, figs. 1 and 2); *Stereum sanguinolentum* (Pl. II, fig. 5); and *Trametes pini*. The first four species mentioned attack hardwoods; the first three are particularly prevalent on aspen. The other fungi attack conifers. Other fungi found only occasionally are *Fomes pinicola*, *Lenzites trabea*, *Trametes heteromorpha*, *Tr. peckii*, *Pleurotus ostreatus*, *Schizophyllum commune*, *Corticium galactinum*, *Stereum rugosiusculum*, and *Hypoxylon cohaerens*. Many others are undoubtedly present, particularly in the southern and western regions. In Sweden (15) *Corticium evolvens* is reported as doing considerable damage to spruce. Those producing heart rot in living trees are *Fomes roseus*, *Fomes pinicola*, and *Trametes pini* in conifers, and *Pleurotus ostreatus* in hardwoods. *Trametes pini* produces the so-called "red heart," or "ring scale."

STORAGE OF PULP WOOD

CHARACTER OF WOOD AVAILABLE FOR PULPING

The principal woods used for pulping are: Spruce, 57 per cent; hemlock, 14.5 per cent; aspen, 6 per cent; balsam fir, 5.4 per cent; and various yellow pines, 5.3 per cent. Other woods used in smaller quantities are jack pine, white pine, white fir, tamarack, basswood, beech, birch, cottonwood, gum, maple, and yellow poplar.

On the whole, the species used are not resistant to decay, for which reason storage of them is difficult. The fact that a certain proportion of the wood reaching the mills is already infected or decayed in varying degrees (see Pl. III, fig. 1) makes the storage of this material even more difficult than that of the sound, since the fungi present at the time of piling will continue to develop rapidly under conditions favorable to their growth.

LENGTH OF STORAGE PERIOD

Most mills aim to carry only a year's supply of wood in the yard, but circumstances often render longer storage necessary. Wood from 2 to 4 years old was found at several mills and it required no specialist to see that such long periods of storage were disastrous under the conditions of piling that obtained. Pulping and chemical tests showed how the wood had deteriorated. Much of the storage loss is preventable by the introduction of better methods of piling and improved sanitation.

Pulp wood supplies, especially east of the Mississippi River, each year come from increasingly great distances from the mills. In some cases they are transported 1,000 miles or more. Much of the supply is at present coming from less accessible, often swampy, regions, where cutting operations are largely dependent on the condition of the terrain—winter being the favorable season for operations. This leads to a seasonal concentration in production and a corresponding congestion at points of delivery, instead of a regular and dependable supply. The growing scarcity of material is also a factor which induces many operators to stock heavily in order to insure adequate material.

The result is very often a heavy influx of timber into yards not equipped to handle it to the best advantage, because of limited space and insufficient labor. Demurrage charges must be kept down, and haste in unloading often leads to improper piling.

Changes can be brought about only by the close cooperation of the pulp-wood producer, the jobber, and the mill operator and his employees. These changes must be based on a thorough knowledge of the causes of decay and the conditions that favor it. It must be fully recognized that the improvements can be effected only if sufficient money is spent for the necessary facilities and labor, and for effective supervision of them.

HANDLING OF PULP WOOD AT WOODS POINTS

Care of pulp wood should start at production points. Observation shows that a large amount of infection and deterioration occurs before the wood reaches its destination.

TIME OF CUTTING

Winter is the best time to cut, since fungous and insect life is largely dormant at this season, and chances of infection are almost negligible. Infection by fungi occurs during warm, moist weather—particularly in the northern regions, in the summer and fall. In the South it may occur at almost any time of the year, but it is especially likely to take place during the rainy season. Since infection occurs

mainly from spores, the most active infection period must coincide with the time of most active production of fruit bodies. In the more northern regions this occurs during the rainy fall months. In low, dense woods it may also occur during the summer. Fruit-body production in the spring months is not so abundant, but at the same time these months are usually so wet that timber can not be seasoned before the active infection period sets in.

REMOVAL OF BARK

Wherever feasible, removal of the bark from pulp wood at production points is strongly recommended. This greatly hastens the seasoning and also prevents insect attack. The bark of hemlock is sometimes removed for use in tanning. This should be encouraged.

METHOD OF PILING

Timber should never be left lying directly on the ground, for woods soil harbors a great variety of fungi, including many wood destroyers. It should be placed on log skids, with the piles separated and preferably built lengthwise to the prevailing winds. An open place on a well-drained slope should be selected wherever possible. Free circulation of the air is the prime consideration. As timber in the woods is much more subject to infection from slash and other rotting débris usually left by the logger, and as even under the best storage conditions available in the woods it can be better handled at the mill, it should be shipped as soon as possible.

STORING OF PULP WOOD AT THE MILL

REMOVAL OF BARK

If bark is not removed in the woods it is desirable, wherever feasible, that it be taken off at the mill before piling. Barked wood dries more rapidly and is less susceptible to insect and fungous attack than wood with the bark on. There is a market for hemlock bark, and its sale may offset the cost of removal.

SEPARATION OF WOOD

Separation of highly perishable species, such as poplar, balsam, and white fir, from the more durable woods may be considered desirable by some operators. In deciding this point, however, it should be kept clearly in mind that improved storage conditions will go far toward eliminating deterioration in mixed piles. The cost of separation will necessarily be considerable, and this item must, of course, be warranted by the returns.

Separation of badly infected shipments (Pl. III, fig. 3) from sound wood is strongly recommended. Although it is not economically feasible to pick out all rotten sticks from shipments of otherwise sound material, something can be done at times in this direction by a diligent yard crew. Badly infected shipments should always be segregated in an allotted portion of the yard for quick utilization. *This precaution is important. Deterioration in such wood is proportionately much greater than in sound or slightly infected stock. If it is intermixed with sound wood it serves as a rapid and vigorous source of infection to the better material.*

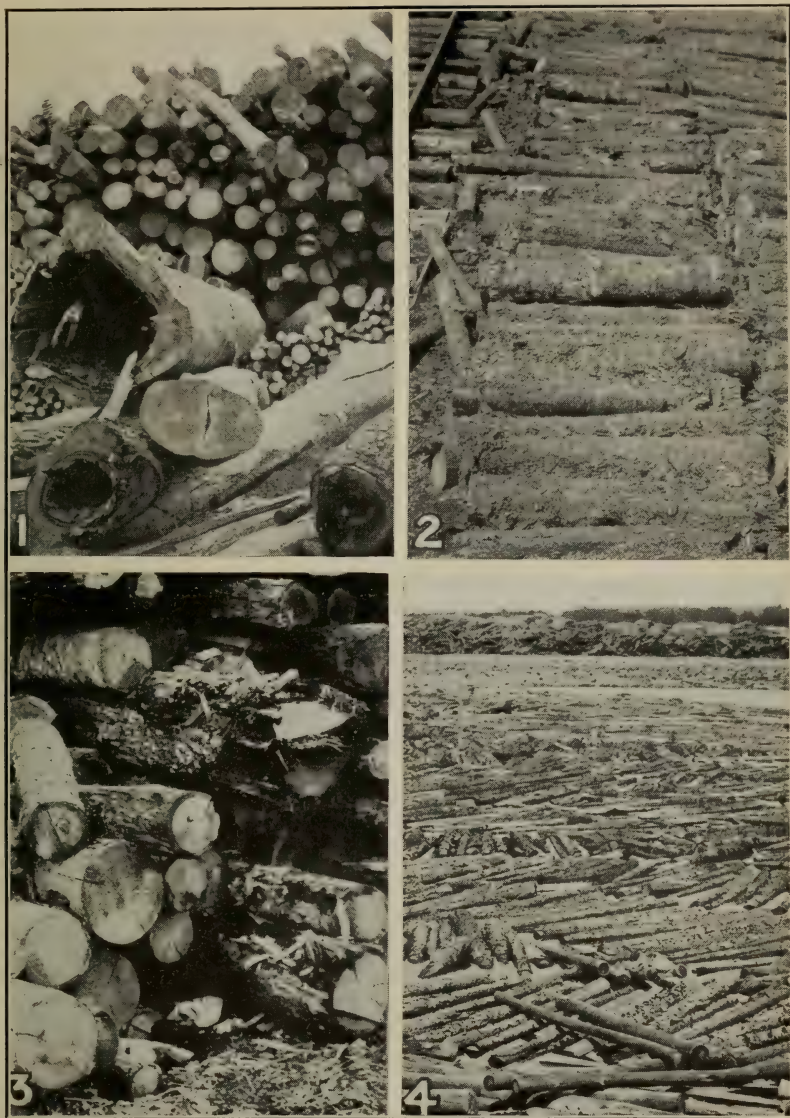


FIG. 1.—Heart-rotted hemlock as delivered to a mill. The largest log is about 3 feet in diameter with a shell of sound wood not exceeding 6 inches in thickness. A large proportion of hemlock is defective from heart rot

FIG. 2.—Bark and insect borings near the base of close-ranked piles of mixed spruce and balsam. Such debris hinders the seasoning process

FIG. 3.—Mixed spruce and tamarack pulp logs seen after they were received at a mill. Note the excessive amount of sap rot. These logs may have been rotten fallen material salvaged from the woods, or the decay may have developed during too long storage previous to delivery. Such wood should never be mixed with sound wood during storage

FIG. 4.—Eight-foot spruce stored in the river. Logs which are not kept saturated will decay

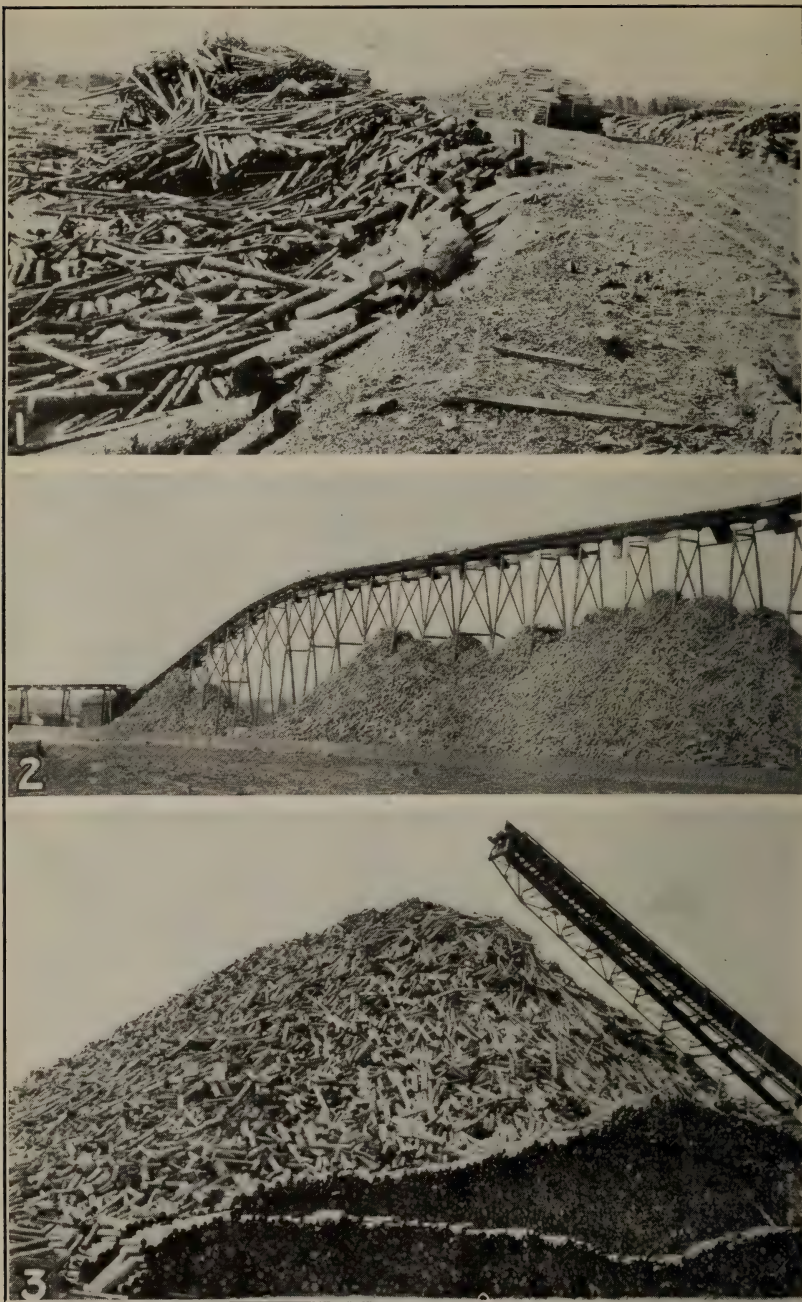


FIG. 1.—Spruce pulp wood unloaded indiscriminately into river, offering very favorable conditions for decay

FIG. 2.—Partial view of conveyor in use for 2-foot wood

FIG. 3.—Pile of 2-foot rossed spruce about 40 feet high and containing about 10,000 cords. The ricked wood in the foreground was so placed for the purpose of establishing a fire lane

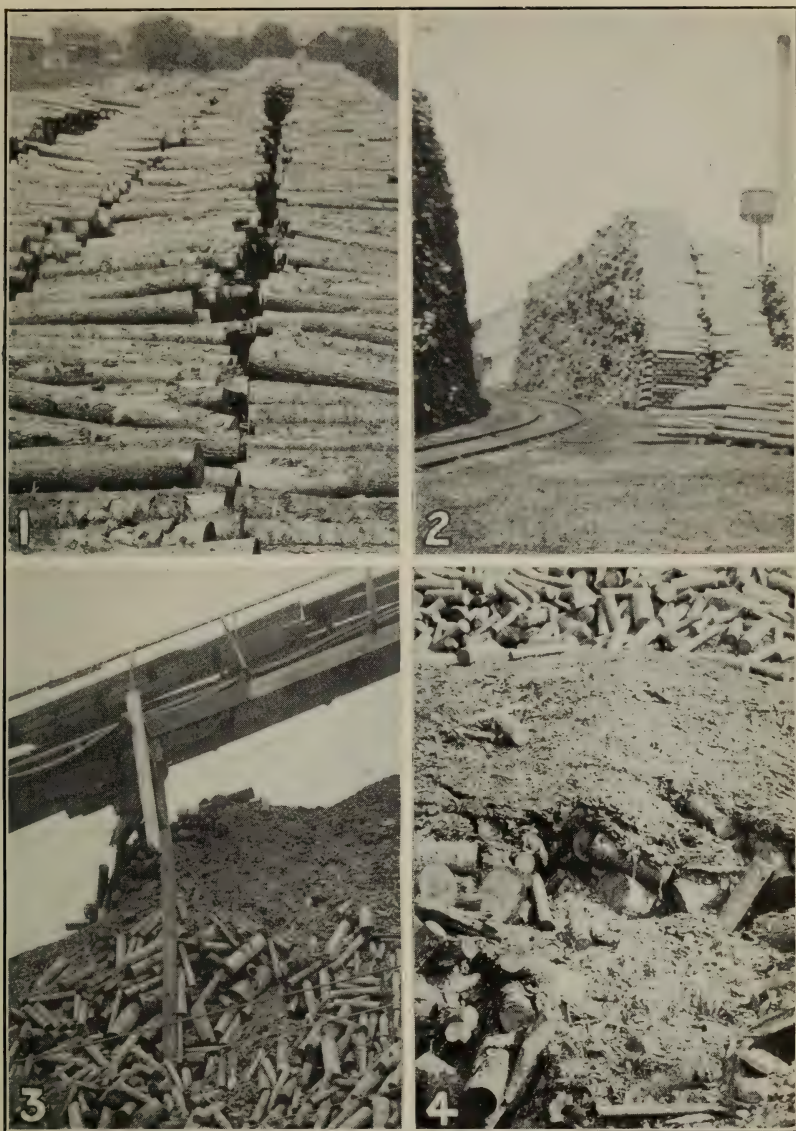


FIG. 1.—Ranked piles of 8-foot spruce. This type of massed piling, without adequate ventilation at the sides and beneath the ranks, leads to serious decay in a comparatively short time

FIG. 2.—Piles 35 feet high of 8-foot jack pine and spruce. Note the orderly arrangement and clean yard, conditions which are all too rare in the pulp industry

FIG. 3.—Bark and fragments of rotten wood which have been shaken down from the conveyor. Such detritus readily absorbs and holds moisture from rains and, in the case of any but water-soaked wood, promotes decay.

FIG. 4.—Bark and rotten wood at the base of a pile of 2-foot spruce and balsam stored for about one and one-half years. New rossed wood has been piled on this old, thoroughly infected base. Considerable loss from decay in the new wood may be expected from this source. Before starting new piles the old wood should be utilized and the surface of the ground cleared of all infecting material



FIG. 1.—Representative samples of infected spruce and balsam taken from the base of the pile shown in Pl. V, fig. 4. These are badly decayed and will be almost worthless when utilized.

FIG. 2.—Pile of pulp wood equipped with spray nozzles spaced 30 feet apart each way and delivering 2 quarts of water per minute. The nozzles should be higher, about 5 to 10 feet above the wood, in order to cover the pile. For the most efficient results and the best distribution of moisture, spray heads should be selected which break the water into the finest possible spray. (After Hoxie)

FIG. 3.—Piles of 8-foot spruce and balsam up to 35 feet in height placed directly on the ground and closely massed. This wood was found very severely decayed after three years' storage.

FIG. 4.—Ranked piles of 8-foot tamarack, about 35 feet high, separated by a space of about 2 feet at the base, which permits considerable air circulation. Higher foundations would be advantageous.

METHODS OF STORAGE

At the mill pulp wood is stored in the open in three ways: (1) In the water (Pl. III, fig. 4 and Pl. IV, fig. 1); (2) in conical piles of 2-foot wood built by means of conveyors (Pl. IV, figs. 2 and 3); and (3) closely ricked in long piles (Pl. V, figs. 1 and 2) up to 30 or 35 feet high.

Complete immersion in water is theoretically ideal storage, because wood in a saturated condition can not rot. In present commercial practice, however, complete immersion is not practicable. Most of the logs float, and often the exposed portion dries out sufficiently for decay to take place. Some logs are left on the river banks at low water; others, as they are unloaded from cars into the river, are left in a high pile extending out into the water. Under such conditions of exposure, wood is very liable to decay, particularly in a zone just above the water line.

In view of the difficulty of keeping the wood saturated, it is believed that storing the logs on well-drained land is preferable to holding them in the river, provided they are properly piled.

Of the two methods of piling pulp wood, ricking seems preferable to piling in large conical piles, provided the ricked piles are off the ground and, especially in the case of the smaller woods and shorter lengths, separated laterally one from another so as to allow continuous circulation of air. With hemlock, however, when stored green with the bark on, piling in close ricks may result in less decay than when the ranks are separated. The conical pile offers the advantage of requiring less space and trackage, but it has drawbacks from a pathological standpoint which, in many cases, can not be eliminated. Its volume is so great that drying takes place only in the outer part, and deterioration is apt to be rapid within. Drying is further retarded by the infiltration of bark debris, which rattles down from the conveyor (Pl. V, fig. 3) or is broken loose from rough wood in dropping. This debris is usually allowed to accumulate (Pl. V, fig. 4), and in time forms an excellent bed in which fungi (Pl. VI, fig. 1) can readily develop. Conical piles are placed directly on the ground, which is usually moist and thoroughly permeated with wood-destroying fungi, with the result that direct infection from the soil occurs. Because drying moist wood in large piles such as these is out of the question, the only alternative is to apply water in the form of a fine spray in an effort to keep the wood *too wet* for decay. Such a procedure, however, can be recommended only when the wood has a high water content at the time of piling.

Hoxie (10, 11, 12) has discussed the relation of moisture to decay and has advocated the use of the spray method (Pl. VI, fig. 2) both as a preventive of decay and as a precaution against fire. As regards moisture in the wood as stored, his observations are:

The character of pulp wood with respect to moisture content varies widely at different mills. Wood which is river driven and is piled out wet after remaining in water for several months contains about 55 per cent moisture, and tests made on chips from this wood after remaining in the pile for one season indicate an average moisture content of from 45 to 50 per cent, which, from best information obtainable, is never below 40 per cent. On the other hand, wood delivered by rail at some mills shows a moisture content as low as 23 per cent.

In the present investigation, moisture determinations were made on a large number of wood samples, both sound and infected, which

had been stored in ranked piles. No data were obtained on fresh river wood; but wet spruce and balsam, after storage in close-ranked piles at one mill for about a year, showed a maximum of 44.4 per cent and an average of 38 per cent. In one instance rotten 3-year-old samples taken from near the bottom of a large storage pile of solidly massed ranks of rail-shipped spruce showed a moisture content of from 33 to 35 per cent, which is practically the same as for green spruce. The top of a similar 35-foot pile ran about 27 per cent. Rotten spruce from another mill, probably stored for about the same length of time but in a much lower pile, was reduced to about 18 per cent. Green wood just off the cars contained about 40 per cent moisture.

The fact that spruce and balsam will rot rapidly in an essentially green condition argues against their storage in large conical piles, unless continuously water-soaked. Hoxie believes that wood with less than 40 per cent moisture is best stored in ranked piles. Snell (25) concludes from experiments with five fungi on spruce that decay is greatest at a moisture content of between 30 and 57 per cent, but that 60 per cent of water will eliminate all danger of serious loss from decay.

Present knowledge of the actual amounts of moisture which will preserve timber is based on observation, or unscientific experimentation. More careful investigations will undoubtedly reveal differences in the reactions of the various wood-rotting organisms toward water. Actual mill tests are highly desirable. It is well established that spruce and balsam containing 35 per cent moisture will decay readily. The few other records available indicate that in certain species considerable decay may also occur up to 80 or 90 per cent moisture content. Above this point the rate of decay may be much reduced.

Wood which reaches the mill in a partially dried condition is probably best stored in ranked piles so that drying may progress to a point where decay is markedly retarded or entirely inhibited. Precautions must be taken to get ample ventilation around and beneath the piles. Under present practices the ranks are often solidly massed without any possibility of air seasoning. (See Pl. VI, fig. 3.) Such a condition should be corrected by separating the ranks by a space of from 4 to 6 feet (Pl. VI, fig. 4) and running them in the direction of the prevailing winds. If they can be placed on a hillside in the direction of the slope, so much the better, as this will allow improved air drainage. Cross ventilation, accomplished largely by free air circulation through the foundations, should be provided for, as this assists in the removal of the humid air near the ground level and hastens seasoning in the bottom of the piles.

Ranked piles are sometimes placed directly on the ground (Pl. VII, fig. 1). In one case they were even piled in a drainage canal (Pl. VII, fig. 2). More often they are placed on parallel rows of poles or logs. The skid logs are commonly taken from the pulp-wood shipments as needed and kept in use as long as they are serviceable, frequently until they are in advanced stages of decay. On moist land they are often forced into the ground so far that sufficient air can not circulate underneath the piles. (See Pl. VII, fig. 3.) Inasmuch as rotten foundations will transmit infection to the wood piled on them, if pulp logs are to be used for foundations it is much better to use fresh logs

for each new pile, removing the old ones and utilizing them for pulp, if suitable. Before new piles are started it is also good practice to rake up and remove all bark debris which has accumulated from the old ones.

A better type of foundation can be made by supporting creosoted stringers on concrete piers or creosoted wood blocks, with the footings sufficiently large to prevent them from being forced into the ground. The supports should be at least 12 inches high to allow ample side ventilation. A concrete foundation experimented with at one of the Wisconsin mills is similar to a rail in section and 10 feet long. The base is 18 inches broad, and the web is provided with 5-inch circular openings spaced 12 inches apart. (See fig. 1.) This has been found of sufficient strength to stand up under the hardest usage it is likely to get with large 12 to 16 foot hemlock logs. (See Pl. VII, fig. 4.)

ROTATION OF WOOD

None of the wood should be held in storage longer than absolutely necessary, for losses during the second and third years are entirely out of proportion to those of the first year. No method of storage which

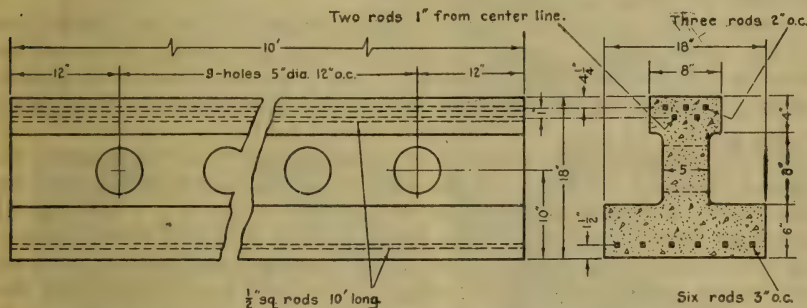


FIG. 1.—Sketch and specifications for precast reinforced-concrete skid in experimental use at a Wisconsin mill

is economically feasible will fully protect wood for long periods, and mills should make every effort to reduce the storage time to a minimum. The time in storage should be reckoned from the date of cutting and due allowance made accordingly in assigning a rotation number, which should be plainly marked on each pile (Pl. VIII, fig. 1) or section of a pile in the yard. The material should always be sent to the wood room in the order indicated. Large conical piles should be completely utilized. New wood should never be piled on old wood at the base. The same attention should be paid to cleaning up bark debris at the bottom of these piles as would be given to ranked piles.

In order that the wood may be piled most conveniently for later utilization, a survey of the yard is highly desirable. Following this, a diagram and blue prints can be prepared for the use of the yard crew, so that a definitely prearranged plan will be available to counteract a tendency toward indiscriminate piling.

GENERAL SANITATION

Many yards are littered with rotten or infected wood or bark debris which should be removed and burned. Infection of new wood may spread from this in two ways, namely, by spores from fruit bodies

developing on it and by direct contact which permits the mycelium to grow from one stick to another. Bark *débris* (Pl. VIII, Fig. 2) and fragments of rotten wood on the ground form an excellent bed for the growth of fungi, since the mass is usually in a moist condition.

The wood which is in too bad condition for pulp should be burned, and noticeably infected wood which is still usable should be segregated and utilized as soon as possible and not mixed in piles with with sound material.

In order to insure better surface drainage (Pl. VIII, fig. 3) and greater cleanliness, it is advisable to surface yards with cinders (Pl. VIII, fig. 4) to a depth of 4 to 6 inches. Incidentally, this will keep down the grass and weeds which impede air circulation around the base of piles.

At most mills the cleaning-up program must be carried out gradually as opportunity permits. Where *débris* has been accumulating for a number of years the task will call for concerted and special effort. In some cases it may even prove advisable to change the location of the yard rather than attempt to put it in satisfactory condition. This would apply particularly to low yards where large amounts of filling are required.

Every yard should be sufficiently drained to insure immediate run-off after rains. Earth is much better for filling than barker waste or other woody *débris*, which if not kept saturated with ground water will soon rot and furnish an uneven and unstable foundation for the piles. In any case the yard should be heavily cindered.

One Wisconsin mill employs a clean-up crew to look after the general sanitary condition of the yard. At least one or two men are continually at work digging out weeds and grass (Pl. VIII, fig. 4), raking up bark *débris*, etc. The wood yard at this mill is well drained and is surfaced with cinders, and there is no appreciable loss from decay during the storage period which is usually not longer than two years. This condition shows quite conclusively the advantages to be derived from a good location and attention to sanitary details.

Spraying the ground beneath piles with a "weak tannic acid solution" (19) or any other antiseptic, is not recommended. Tannic acid is not an effective fungicide, and treatment with an effective antiseptic is too expensive in proportion to the benefits derived.

SUMMARY OF RECOMMENDATIONS

It is believed that if the recommendations just given are consistently followed, losses in stored wood can be for the most part prevented. The big outstanding fact is that present conditions, wherever they favor fungous attack, must be corrected before mills can hope to eliminate deterioration from these causes. The extent of loss in the wood yard has never been fully realized. All other operations about the mill are closely scrutinized, and are corrected wherever losses are exposed. Why except the wood yard? It may require expert assistance to get the best results, but once the system gets under way it becomes largely a question of close attention to detail. Money will have to be spent, just as it must be spent in the replacement of old machines with more modern ones in order to meet close industrial competition. Taking as a very conservative estimate a shrinkage in value of \$1 to \$1.50 per cord for wood cut one and one-

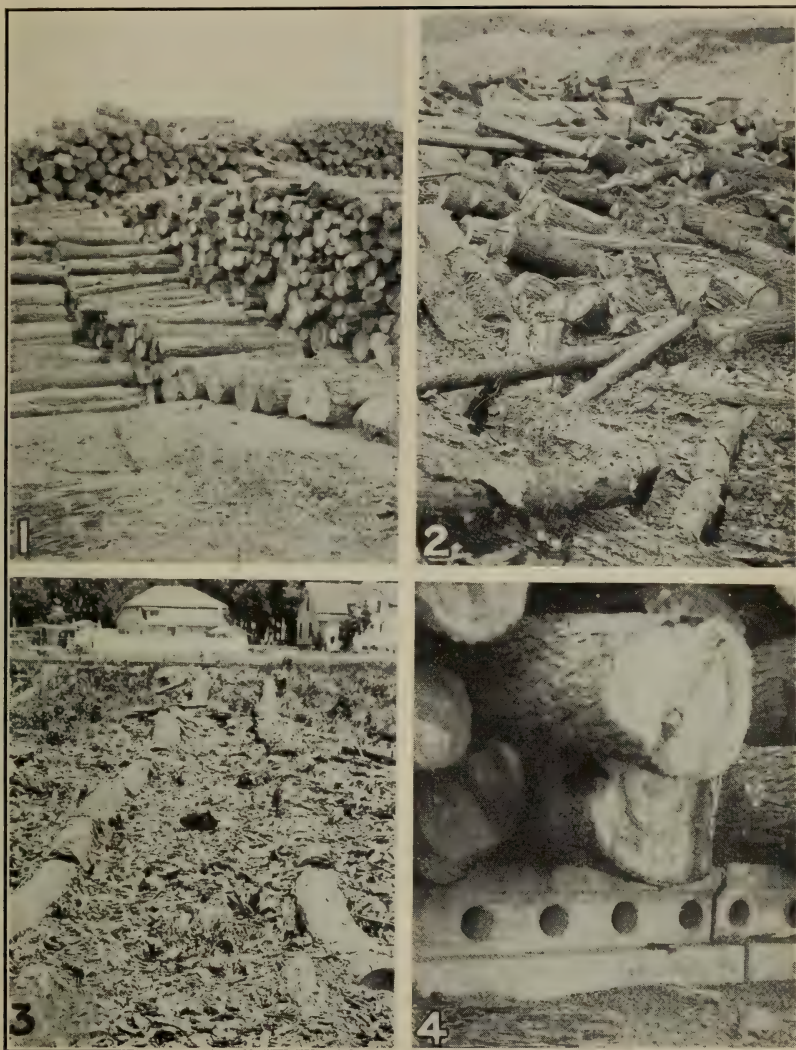


FIG. 1.—Four-foot hemlock piled directly on the ground and with no spacing between the ranks. Wood should never be placed directly on the ground. Even if these ranks had been separated, the pile in the background running at right angles to them would have cut off most of the air circulation

FIG. 2.—Hemlock pulp logs 12 to 14 feet long piled in a drainage canal 12 feet deep. The logs which are not wholly submerged will decay with extreme rapidity, owing to the moisture conditions being favorable to decay and the impossibility of further drying

FIG. 3.—Hemlock logs used as foundations for 12 to 14 foot pulp wood. The accumulation of bark from the handling and peeling of logs is nearly at the top of the rotten foundations, so that the wood might about as well be piled on the ground. The whole mass is an excellent fungus bed

FIG. 4.—Concrete skid, built according to the sketch shown in fig. 1 (p. 11), in experimental use at a mill

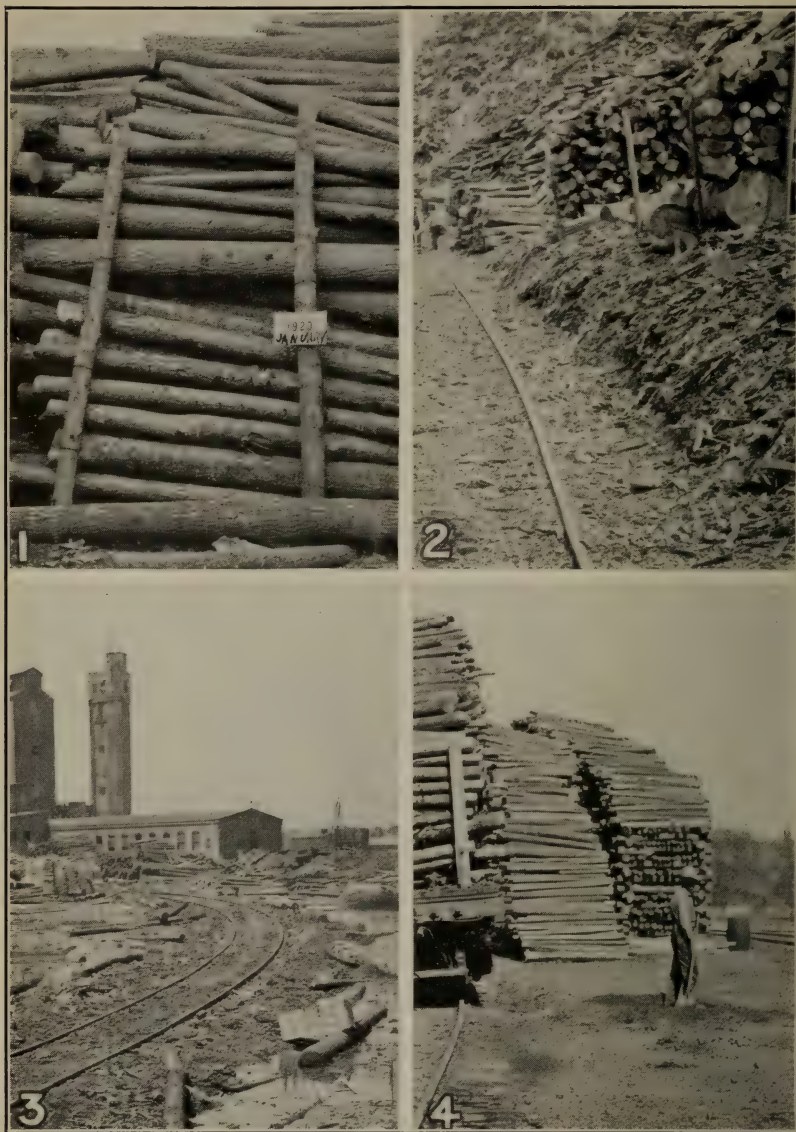


FIG. 1.—Pulp wood piles marked with date of arrival at the mill, to be used in rotation

FIG. 2.—Bark accumulation resulting from the hand peeling of hardwoods, a source of infection to wood piled on it. It was several feet thick over the entire yard

FIG. 3.—A storage yard on swampy ground. Pulp and pulp wood can not be stored under such conditions without heavy loss. Certain portions of the yard were being raised several feet with barker waste, surfaced with cinders. Earth and cinders would serve the purpose much better

FIG. 4.—Wood yard surfaced with cinders and located on a well-drained slope. The company recognizes the value of cleanliness and employs a crew to rake up and remove all accumulated bark and rotten wood. Workman "spudding" out grass and weeds and leveling the cinders. Wood is not usually stored longer than a year, and there is no appreciable loss from decay

half to two years, the losses for an average mill will be a very considerable item. As these can largely be prevented through the improvement of storage conditions, at least part of the money represented in losses might well be invested for their prevention.

The points to be emphasized in handling pulp wood are:

1. Timber should be left in the woods the shortest possible time, and while it is there it should be stored on skids, on a well-drained site fully exposed to the wind, in separate piles running, preferably, in the direction of the prevailing winds.

2. If borers are troublesome, soaking in water and peeling are effective.

3. Logs should, if possible, be peeled, in order to hasten air drying and also to prevent borers from attacking the wood.

4. Badly infected shipments or portions of shipments should be separated from sound wood and segregated for rapid utilization.

5. Wood should be stored at the mill on well-drained land. The site should have a cindered surface which will give rapid run-off and keep down weeds which hinder air circulation around the base of piles. Barker waste is a poor filling material, because it harbors fungi and forms a very unstable foundation for piles, even when surfaced with cinders.

6. Conical piling by the use of conveyors is not considered as good as ricking for partially dried wood. For river wood it seems satisfactory, when the piles are equipped with an overhead spray system to keep the surface moist. The method needs testing under commercial conditions, however, in order to determine more exactly the percentage of moisture in the wood necessary for protection. The sprays are also valuable features for fire prevention.

7. Wood should never be ricked directly on the ground. The best procedure is to use reinforced concrete skids provided with sufficient openings to insure good cross-ventilation or concrete piers supporting stringers which have been given a pressure treatment of coal-tar creosote. If treated properly, either of these types should last 20 to 25 years. The latter is preferred because it gives better cross-ventilation. If it is not considered feasible to equip the yard with concrete piers, the next best method would be to use wood blocking, pressure-treated with coal-tar creosote, as supports for the stringers. The stringers should, in any case, be at least 12 inches, preferably 18 inches, off the ground. If pulp logs are used they should be of the larger sizes and should be pulped or removed when the piles are torn down.

8. High-ranked piles should, as a rule, be separated by open spaces 4 to 6 feet wide and with their length in the direction of the prevailing winds. Between low piles a 3 to 4 foot space should be sufficient.

9. Each pile should be marked with the date on which it was piled, or if possible with the date of cutting. The piles should be used in the order they were cut.

10. All decayed and unserviceable wood should be removed from the yard, and after the removal of a pile of wood the bark should be cleaned up.

PULPING CHARACTERISTICS OF DECAYED WOOD

PHYSICAL PROPERTIES OF MECHANICAL PULP MADE FROM SOUND AND DECAYED SPRUCE

CHARACTER OF WOOD USED

In order to demonstrate the large losses sustained and the difficulties encountered in the use of decayed wood, comparative grinder runs were made on sound and on decayed spruce wood at one of the cooperating mills.

The sound wood, sample 1 (Pl. IX, fig. 1), was 12-foot Wisconsin spruce taken direct from a car which had just been received at the mill.

The decayed wood, sample 2546 (Pl. IX, fig. 2), represented ordinary mill-run Minnesota spruce, approximately 3 years old. It had been stored in 8-foot lengths directly on the ground, in close ricks, in a solid mass of several thousand cords. (See Pl. VI, fig. 3.) The logs used for the grinder runs were selected from the lower half of the piles. They were representative of severely infected material, but no wood was so badly decayed that it would have been rejected by the mill.

The principal fungi rotting the wood, in the order of their frequency, were *Fomes roseus*, *Stereum sanguinolentum*, *Polystictus abietinus*, *Lenzites sepiaria*, and *Trametes pini*. A tally of 184 of the 250 sticks showed 75 sticks infected with the first fungus, 59 with the second, 28 with the third, 16 with the fourth, and 6 with the fifth. *Fomes roseus* was represented in the living tree to a certain extent as a heart-rotting organism, but most of the rot probably developed in the pile. *Trametes pini* was undoubtedly introduced altogether as heart rot from the standing tree. All the other fungi developed from infections subsequent to cutting. Of these, *Lenzites sepiaria* readily attacks both heartwood and sapwood; *Stereum sanguinolentum* and *Polystictus abietinus* attack the sapwood principally.

METHOD OF PREPARATION

Approximately 5 cords each of infected and sound wood were selected, weighed, and ricked. This material was then sampled by cutting disks 6 inches thick for specific gravity determinations (Pl. IX, fig. 3) and thinner disks for moisture determinations. The moisture disks were weighed directly after cutting, wrapped in paper to prevent loss of small particles of bark and wood, and sent by express to the laboratory for the actual moisture determination. Fourteen of the sound and 26 of the infected sticks were sampled in this manner.

After being sampled the logs were dumped into the hot pond and cut into 2-foot bolts, all the odds and ends being collected and weighed and this weight deducted from the weight of the rough wood. The 2-foot bolts were barked on knife barkers and corded in cord ricks.

Preliminary to grinding, the ground-wood chest was run dry and washed out. Two 3-pocket grinders were used, with a pressure of 35 pounds per square inch on the piston heads and an average speed of 220 revolutions per minute. The stones were sharpened equally for

both runs. The temperature of grinding varied between 120 and 180° F. (49 to 82° C.). After the separated screenings were weighed the pulp was run over the wet machine and the dry weight calculated.

The essential data obtained from these tests are shown in Table 1.

TABLE 1.—*Data on the grinding of sound and decayed spruce*

	Sound wood, sample 1	Decayed wood, sample 2546
Quantity of wood.....pieces..	1 140	2 250
Weight of rough wood.....pounds..	17, 920	18, 839
Weight of rough wood, oven-dry ³.....do.....	10, 720	12, 600
Loss in barking, based on oven-dry wood.....per cent..	32.4	31.3
Weight of barked wood, oven-dry.....pounds..	7, 250	8, 650
Yield of pulp, oven-dry weight.....do.....	6, 826	6, 783
Yield of oven-dry pulp, based on oven-dry barked wood.....per cent..	94.2	78.4
Yield of oven-dry pulp, based on oven-dry rough wood.....do.....	63.7	53.8

¹ 12-foot lengths.

² 8-foot lengths.

³ Computed from moisture samples.

YIELD AND QUALITY OF PULP

The results of this particular trial indicate a yield of 94.2 per cent in the case of the sound and of 78.4 per cent in the case of the decayed wood, on the basis of oven-dry weights in each case. Decay thus accounts for a loss of 15.8 per cent.

A sample of the pulp from each grinder run was shipped to the Forest Products Laboratory for physical and microscopic examination and for paper-making trials. Samples were also placed in moist storage for further observation, as described later.

Sedimentation tests indicated that the pulp made from decayed wood was slightly freer than that made from sound wood, although the difference was not marked. Microscopic examination of the average length of fiber particles showed 1.57 millimeters for the sound in comparison with 1.27 millimeters for the decayed material. The decayed pulp contained about twice as much débris, in the form of very small particles evidently produced by pulverizing the infected wood in the grinding. A large percentage of this débris would, of course, be lost during conversion on the paper machine, so that white water losses from decayed pulp should be larger than for sound pulp.

The stock was run into 100 per cent ground-wood sheets without the use of size, alum, or color. Physical tests on the papers, as shown in Table 2, indicate that both stocks, in so far as these runs would show, were of about the same strength. The pulp made from decayed wood, however, contained the larger number of shives and was decidedly the darker of the two in color.

TABLE 2.—*Data on waterleaf papers made from sound and from decayed spruce woods*

Sample No.	Description	Weight of ream, 24 by 36—500	Points per pound per ream	Average breaking length	Average stretch	Temperature	Humidity
		<i>Pounds</i>		<i>Meters</i>	<i>Per cent</i>	<i>° F.</i>	<i>Per cent</i>
1AA...	From sound wood, No. 1.....	47	0.304	2, 760	1.4	87	64.5
2AB...	From decayed wood, No. 2546....	48	.304	2, 610	1.3	85	64.0

PHYSICAL PROPERTIES OF SULPHITE AND SODA PULPS MADE FROM SOUND AND FROM DECAYED WOOD

CHARACTER OF WOOD USED

Investigations were made at the Forest Products Laboratory to determine the effect of decay in wood on the yield and on the quality of chemical pulps made from it, and to ascertain the difficulties encountered in manufacturing paper from such pulps.

Through the courtesy of the cooperating mills, shipments of spruce, hemlock, and aspen woods representing sound wood and wood in various stages of decay were received. These woods may be described as follows:

Sample 2545. Spruce wood from a Wisconsin mill; nearly free from decay; taken from the top of a pile approximately 35 feet high, containing about 10,000 cords of 8-foot wood. Used for sulphite cook No. 7, pulp designated as No. 2547.

Sample 2546. Spruce wood; considerably decayed; taken from the bottom of the same pile from which No. 2545 was taken. Used for sulphite cook No. 6, pulp designated as No. 2548.

Sample 2560. Spruce wood from a Wisconsin mill; nearly free from decay and in physical appearance similar to No. 2545. Used for sulphite cooks Nos. 8 and 10, pulp designated 560A and 560, respectively, and for soda cook No. 6, pulp designated as No. 2559.

Sample 2541. Spruce wood from a Wisconsin mill; so badly decayed that it was rejected at the pulp mill. (See Pl. IX, fig. 4.) Used for sulphite cook No. 9, pulp designated as No. 2555, and for soda cook No. 7, pulp designated as No. 2557.

Spruce wood, not numbered; presumably sound; received at the Forest Products Laboratory and cooked prior to these studies. Used for sulphite cook No. 336, pulp designated as No. 2540.

Spruce wood, not numbered; presumably sound; received at the Forest Products Laboratory prior to these studies. Used for soda cook No. 109, pulp designated as No. 540.

Sample 2552. Aspen wood selected at random from a Michigan mill pile; extent of decay not certain. Used for sulphite cook No. 1, pulp designated No. 5521, and for soda cook No. 4, pulp designated as No. 552D.

Aspen wood, not numbered; presumably sound; received at the Forest Products Laboratory and cooked prior to these studies. Used for sulphite cook No. 351, pulp designated as No. 50.

Sample 2542. Hemlock wood from a Wisconsin mill; considerably decayed; used for sulphite cooks Nos. 2, 3, and 5, pulps designated respectively 542A, 542B, and 542C, and for soda cook No. 3, pulp designated as 542D.

Sample 2554. Hemlock wood from the same mill from which No. 2542 was received; sound; used for sulphite cook No. 4, pulp designated as No. 554.

Hemlock wood, not numbered; presumably sound; received at the Forest Products Laboratory and cooked prior to these studies. Used for soda cook No. 228, pulp designated as No. 40.

CHIPPING LOSSES

On account of the breaking down of the fibers by the fungi, decayed wood is brash. In the chipping of such wood a considerable loss occurs in "sawdust" and shives which are rejected by the screens. Trial chipping and screening of sound and decayed spruce wood from the lot under investigation gave the following screening losses in per cent by weight:

	Per cent loss
Sound	4.4
Relatively sound (No. 2545)	5.6
Somewhat decayed (No. 2560)	13.2
Considerably decayed (No. 2546)	15.6
Badly decayed (No. 2541)	17.0



FIG. 1.—Fresh sound spruce used for experimental grinding in comparison with the infected wood shown in fig. 2

FIG. 2.—Rick of infected spruce wood used for experimental grinding. This was representative of the material toward the base of the pile shown in Pl. VI, fig. 3

FIG. 3.—Specific gravity disks cut from the infected spruce shown in fig. 2. Sample 23 was decayed by *Lenzites sepiaria* and *Polystictus abietinus*, sample 21 by *Stereum sanguinolentum*, and sample 19 by a fungus which was not fruiting and hence indeterminable

FIG. 4.—Spruce wood about four years old sent to the laboratory for sulphite and soda cooking tests. This wood was rotted mainly by *Fomes roseus* and was too far gone for commercial use

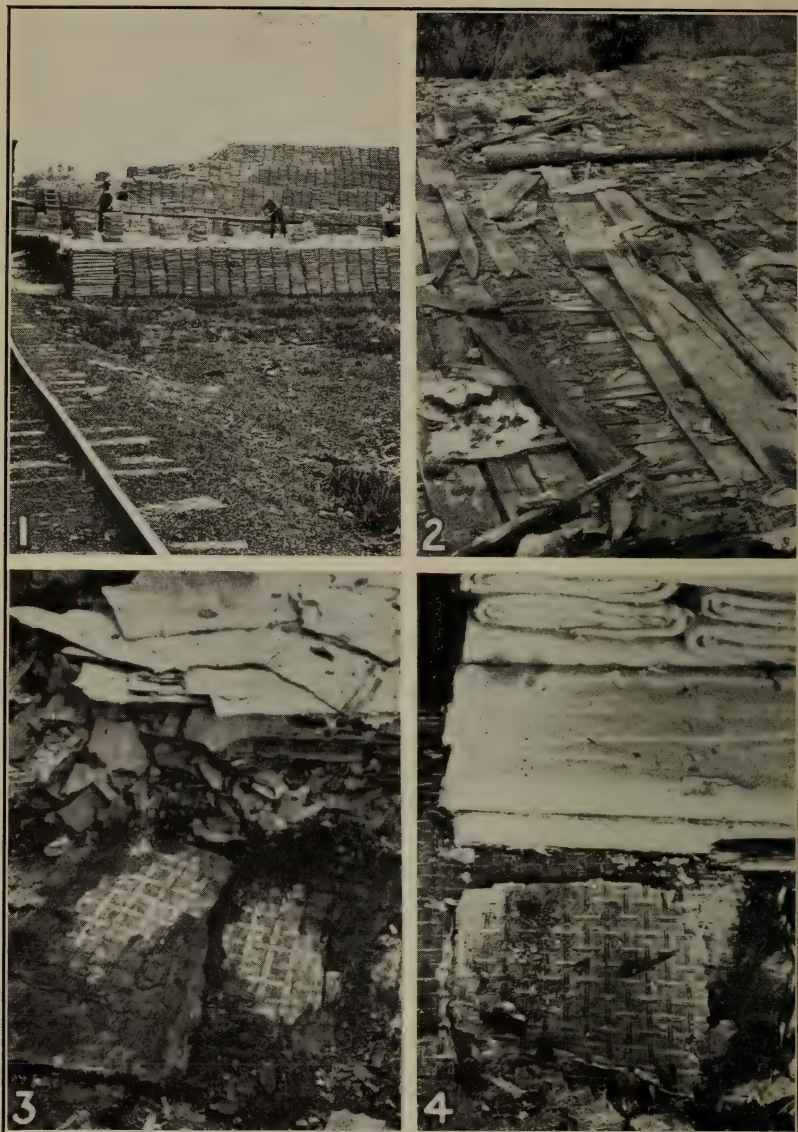


FIG. 1.—New ground-wood pulp placed directly on ground. A concrete base would prevent all infection from the ground upward into the base of the pile.

FIG. 2.—Rotten platform recently used for ground wood. It rests directly upon moist soil, from which it became infected. If plank foundations are to be used, all decaying material should first be removed from the site, the ground surfaced with cinders, and fresh new timber used for each pile. In the long run a concrete base will be found much better and cheaper.

FIG. 3.—Base of a pile of hydraulic-pressed ground-wood pulp stored two years in an open shed. The light area to the right is a very rotten spot in the floor, from which the piece of pulp to the left has been turned back. The indication is clear that this particular decayed area in the pulp originated from the floor.

FIG. 4.—New ground-wood pulp stored on a rotten base consisting of hydraulic-pressed ground-wood pulp two years old. The floor is also completely decayed. Under no circumstances should clean pulp be placed in contact with decayed or infected material.

Even though the equipment used in this instance is not comparable with mill equipment, the results show the relative effect of decay upon this type of loss.

PREPARATION OF SULPHITE PULP

Both sound and decayed spruce, hemlock, and aspen were cooked by the sulphite process in the laboratory digester, under conditions as nearly uniform as possible. In Table 3 are indicated the conditions of cooking and the respective yields. The data on cooks Nos. 351 and 336, of sound aspen and sound spruce, respectively, were taken from the laboratory records of previous tests and were used for purposes of comparison.

TABLE 3.—*Sulphite cooks of sound and decayed woods*

[Yield percentages are based on oven-dry weights of wood and pulp]

Sample No.	Cook No.	Pulp No.	Description	Time of cook	Max. temp.	Total SO ₂	Free SO ₂	Combined SO ₂	Yield of crude pulp	Yield of screenings	Yield of screened pulp	Bleach (35 p.ct. avail. chlorine)
				Hours	° C.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
-----	336	2540	Spruce, sound.....	8. 25	153	5. 86	4. 56	1. 30	47. 1	0. 4	46. 7	14
2545	7	2547	Spruce, decayed.....	8	152	5. 34	4. 10	1. 24	44. 6	. 8	43. 8	14
2560	8	560A	do.....	8	155	5. 50	4. 37	1. 13	47. 4	. 6	46. 8	16
2560	10	560	do.....	8	153	5. 50	4. 35	1. 15	45. 9	. 8	45. 1	16
2546	6	2548	do.....	8	152	5. 45	4. 28	1. 17	43. 9	. 4	43. 5	14
2541	9	2555	do.....	8	153	5. 56	4. 45	1. 11	39. 6	1. 2	38. 4	20
2554	4	554	Hemlock, sound.....	8	153	5. 38	4. 36	1. 02	46. 6	. 5	46. 1	36
2542	2	542A	Hemlock, decayed.....	8	152	5. 44	4. 33	1. 11	44. 9	. 7	44. 2	26
2542	3	542B	do.....	8	153	4. 92	3. 83	1. 09	46. 6	. 8	45. 8	35
2542	5	542C	do.....	8	153	5. 36	4. 27	1. 09	46. 8	. 7	46. 1	44
-----	351	50	Aspen, sound.....	8. 25	152	5. 50	4. 20	1. 30	47. 5	. 1	47. 4	12
2552	1	5521	Aspen, decayed.....	7	153	4. 28	3. 14	1. 14	42. 1	. 0	42. 1	19

PREPARATION OF SODA PULP

Soda cooks were made only on decayed specimens of the three woods. The cooking conditions were maintained as nearly uniform as possible except in the case of the aspen, for which a larger amount of chemical was used. In Table 4 are given the cooking data. The data shown for cooks Nos. 109 and 228, on sound spruce and sound hemlock, respectively were taken from the laboratory records for purposes of comparison.

YIELD OF PULP

The yield of screened sulphite pulp obtained from the decayed spruce woods did not vary greatly from each other, except in one case, nor were they much lower than the yield from sound spruce. The exceptional yield, which was abnormally low, was that from the rejected wood, No. 2541. None of the hemlock woods was sufficiently decayed to show a pronounced decrease in yield. The aspen pulps showed a lesser yield with greater amount of decay.

TABLE 4.—*Soda cooks of sound and decayed woods*

[Yield percentages are based on oven-dry weights of wood and pulp]

Sam- ple No.	Cook No.	Pulp No.	Description	Maxi- mum steam pres- sure	Time at maxi- mum pres- sure	Total time of cook	NaOH per 100 pounds oven- dry chips	Liquor per 100 pounds oven- dry chips	Alkali con- sumed	Yield of crude pulp	Yield of screen- ings	Yield of screened pulp
				<i>Lbs.</i>	<i>Hrs.</i>	<i>Hrs.</i>	<i>Pounds</i>	<i>Gallons</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
2560	109 6	540 2559	Sound spruce. Decayed spruce.	100 100	$\frac{1}{2}$ 5	2 $\frac{1}{2}$ 6	20.3 20.5	27.4 31.6	75.9 89.9	50.2 42.6	1.4	48.8 42.6
2541	7 228	2557 40	do. Sound hem- lock.	100 105	5 $\frac{3}{4}$	6 4 $\frac{1}{2}$	20.5 20.5	31.7 27.2	95.9 82.0	48.8 46.0	16.8 0.1	32.0 45.9
2542	3	542D	Decayed hem- lock.	100	5	6	20.5	31.4		45.5		45.5
2552	4	552D	Decayed as- pen.	102	4 $\frac{1}{2}$	5 $\frac{1}{2}$	26.2	30.3	95.3	44.0	4.9	39.1

In the soda process the yields of spruce pulps showed a wider range than those for sulphite, with the rejected spruce wood again giving an abnormally low yield. The aspen wood, No. 2552 (pulp No. 552 D), yielded only 39.1 per cent, notwithstanding the use of an exceptionally large proportion of chemical. Badly decayed wood is soluble to a high degree in caustic soda solution, so much so that during the early stages of cooking the concentration of the active alkali is reduced to such an extent that the pulping process can not be completed. The result is a large percentage of screenings and a low yield of screened pulp. For example, the badly decayed spruce wood, No. 2541, was soluble in caustic soda (see Table 7) to the extent of 62.3 per cent. It was found by repeated trials that the 20.5 pounds of alkali sufficient to pulp 100 pounds of sound wood was insufficient for this decayed spruce, the yield from which (pulp No. 2557) consisted of 16.8 per cent of screenings and only 32.0 per cent of screened pulp.

Attention should be directed to the fact that these yields are expressed on an oven-dry weight basis both for the wood and the pulp. *If it had been possible to convert the yields to a pounds-per-cord basis, a distinct lowering of yield with increasing decay would doubtless have been evident even in the less extreme cases.* Such a conversion involves two factors: The density of the wood, and the solid wood volume per cord. Both factors, even for sound wood, show wide variation, so that any figures given for the yield per cord would be practically meaningless. If solid volume, rather than the number of cords, be taken as the basis, then density becomes the chief factor to be considered; and of two woods of different densities but yielding equal weights of pulp, that with the lower density will, obviously, show the lower yield per unit volume.

Comparisons on that basis would be fairly exact but for the fact that data on the density of the woods used for the pulping tests are insufficient, and in some cases apparently conflicting; nevertheless they indicate, in general, that the progress of decay is accompanied by a decrease in density. This is certainly true in the advanced stages of decay, and the decrease in average density is doubtless roughly proportional to the increase in decay. Further investigation of this point would be very desirable because of its direct and vital bearing upon mill operation.

The decayed aspen used in the tests weighed approximately 2 pounds less per cubic foot than sound wood. To put the matter in another way: If 100 solid cubic feet of sound aspen had been purchased and placed in storage until decay had reduced its density to this extent, 200 pounds of wood would have been lost; and even though a yield (on the weight basis) were obtained equal to that for sound wood, say 40 per cent, the actual loss of 80 pounds per 100 cubic feet would be there just the same.

QUALITY OF PULP

The screened pulps from both the sulphite and the soda cooks were converted into waterleaf paper on the experimental paper machine, and the papers were tested for strength. The data appear in Table 5.

TABLE 5.—Strength tests of sulphite and soda pulps made from sound and from decayed woods

Sample No.	Cook No.	Description	Weight of ream, 24 by 36—500	Mullen test	Points per pound per ream	Breaking length	Folds	Stretch	Atmospheric conditions	
									Relative humidity	Temperature
			Pounds	Pounds		Meters	Number	Per cent	Per cent	° F.
2540	336	Sulphite pulp:								
2547	7	Sound spruce	43.5	32.0	0.74	5,880	785	2.90	65	94
560A	8	Decayed spruce	41.5	26.8	.65	5,480	310	1.58	64	92
560	10	Do.	39.5	25.4	.64	5,630	121	1.88	64	92
2548	6	Do.	38.0	25.4	.67	6,040	207	1.69	64	77
2555	9	Do.	38.0	25.9	.68	5,070	169	1.83	64	92
554	4	Do.	30.0	17.8	.59	4,370	26	1.62	64	93
542A	2	Sound hemlock	47.6	32.2	.68	6,660	449	3.46	66	75
542B	3	Decayed hemlock	37.0	14.7	.40	4,490	137	1.90	67	72
542C	5	Do.	39.5	25.8	.65	6,170	232	2.54	65	75
50	351	Do.	38.5	21.7	.56	5,950	306	2.58	66	75
5521	1	Sound aspen	51.2	25.6	.50	3,970	12	1.87	65	74
		Decayed aspen	44.5	11.4	.26	3,760	5	1.66	66	68
		Soda pulp:								
540	109	Sound spruce	40.0	28.8	.72	5,490	707	1.97	65	-----
2559	6	Decayed spruce	46.0	21.0	.46	4,770	192	1.44	65	79
2557	7	Do.	76.5	25.2	.33	2,790	1	1.08	66	82
40	228	Sound hemlock	43.5	37.3	.86	6,390	668	3.26	68	69
542D	3	Decayed hemlock	46.5	24.3	.52	5,380	389	3.32	64	77
552D	4	Decayed aspen	40.5	11.8	.29	3,290	4	1.64	65	72

All of the pulps made from decayed woods show a lower strength than those made from sound wood, as indicated by the bursting and breaking-length tests. The breaking length for pulp No. 560, from decayed spruce, was the only exception to this rule. The low endurance of folding shown by the pulps from decayed woods is very marked, and is indicative of the decidedly deteriorating effect which decay in wood has upon the flexibility and wearing qualities of pulps made from it. This deterioration is especially marked in sulphite pulp No. 2555, made from the badly decayed spruce wood. Moreover, the pulp was exceptionally dirty. When this same wood was cooked by the soda process the strength of its pulp, No. 2557, was even lower, and the pulp was again very dirty in color.

CHEMICAL PROPERTIES OF SOUND AND DECAYED WOODS AND PULP FROM SOUND AND DECAYED SPRUCE

A knowledge of the chemical composition of sound woods and pulps and of the changes produced in them by the action of fungi is of considerable importance to an understanding of the losses sustained during the storage of such material and in the conversion of wood into pulp and of pulp into paper. In following the earlier stages of decay, in particular, chemical analysis is superior to visual examination, for an infected log or lap of pulp may look relatively sound and yet contain wood-destroying fungi which had chemically changed the fiber, rendering it of distinctly less value as a paper-making material. For these reasons sound and decayed specimens of spruce, hemlock, balsam, and aspen woods and of pulps from sound and decayed spruce were subjected to chemical analysis, the object of the investigation being to correlate, more definitely than ever before, and quantitatively where possible, the chemical evidences with the fact and the degree of wood and pulp decay.

The analytical methods used were those that have been found of value in the study at the laboratory of the chemistry of woods, details of procedure having appeared in the technical journals in various articles³ initiated by the laboratory. The methods cover determinations for moisture; ash; solubility in cold water, in hot water, in 1 per cent NaOH, in 7.14 per cent NaOH, in alcohol, and in ether; lignin; cellulose; alpha, beta, and gamma cellulose in the total cellulose; pentosans; methyl-pentosans; and copper number.

SPRUCE WOOD AND SPRUCE MECHANICAL PULP

SOUND SPRUCE WOOD

In order to establish a check in the present studies, cross sections of spruce logs were obtained from various parts of eastern North America and analyzed for lignin, cellulose, and solubility in ether and in alcohol. These data, together with the number of annual rings in each log sampled, are recorded in Table 6. The samples were inspected microscopically and found to be sound, except as indicated in the table. The lignin showed variation from 26.8 per cent to 28.3 per cent, and the cellulose from 58.1 per cent to 61.7 per cent. Whether these variations are indicative of differences due to the locality of growth it is impossible to say from the limited data. All of the Canadian and New England samples tested were relatively high in cellulose content, and those from Wisconsin and lower Michigan relatively low. The decayed spruce woods studied were mostly from Wisconsin. If locality were known to exert an influence on cellulose content, the average of the values for cellulose given in Table 6 would be too high for general comparison, and losses in cellulose due to decay would be over-accentuated. The more conservative value, 58.5 per cent, obtained for the Wisconsin sample designated VA was therefore chosen as a standard for comparison.

³ Schorger, A. W., Jour. Ind. and Eng. Chem. 9: 556. 1917.

Mahood, S. A., and Cable, D. E., Jour. Ind. and Eng. Chem. 12: 873. 1920.

Mahood, S. A., and Cable, D. E., Jour. Ind. and Eng. Chem. 14: 727. 1922.

Bray, M. W., and Staidl, J. A., Jour. Ind. and Eng. Chem. 14: 35. 1922.

TABLE 6.—*Chemical analyses of samples of sound white spruce wood from various parts of North America*

Designation of sample	Company and locality	Moisture	Lignin	Cellulose	Ether soluble	Alcohol soluble	Number of annual rings	Condition as observed under microscope
		<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. in.</i>	
VIIC-----	Port Huron Sulphite & Paper Co., Edmonton, Alberta, Canada.	3.3	26.8	61.7	0.7	0.4	64	Occasional thread of mycelium.
VIIIB-----	Riordon Co. (Ltd.), Hawkesbury, Ontario, Canada.	4.5	28.0	61.1	.7	1.0	110	Do.
XIIIB-----	Price Bros. Co. (Ltd.), Kenogami, Quebec, Canada.	5.0	27.4	60.9	1.5	.9	23	Sound.
XB-----	Laurentide Co. (Ltd.), Grand Mere, Quebec, Canada.	4.9	28.1	60.5	1.5	.9	40	Do.
VIA-----	Groveton Paper Mills Co., Groveton, N. H.	5.0	28.1	60.7	.8	1.1	47	Do.
IVA-----	S. D. Warren Co., Cumberland Mills, Me.	4.4	26.9	60.1	.6	.8	75	Do.
Id and Ig-----	Pejepscot, 10 miles north of Brunswick, Me.	4.2	26.8	59.7	.6	.8	18	Do.
IXA-----	Hammermill Paper Co., Fort William, Ontario, Canada.	3.6	27.6	59.3	.7	1.1	85	Do.
VA-----	Marathon Paper Mills, Rothschild, Wis.	3.1	28.3	58.5	1.2	.8	80	Do.
IIIA and bx-----	Fletcher Paper Co., Alpena, Mich.	4.2	27.9	58.1	.9	1.0	27	Occasional thread of mycelium.

DECAYED SPRUCE WOOD

Spruce woods, Nos. 2545, 2546, and 2541, previously described in connection with the pulping tests and representing decay in increasingly advanced stages, together with two additional samples, were analyzed by the methods used for the sound wood VA. The additional samples were No. 2549, a Minnesota wood nearly free from decay, and No. 2556, a Minnesota deadhead log taken from the bottom of the river. In Table 7, following the data for sound wood VA, are presented the data for decayed woods, arranged in the order of decreasing cellulose content. This is also the order of increasingly advanced stages of decay as evidenced by the general appearance of the specimens. Of the five, however, only No. 2541 was so far gone that it had been rejected at the mill.

TABLE 7.—*Analyses of sound and decayed spruce woods*

Sample No.	Description	Cold water soluble	Hot water soluble	Ether soluble	1 per cent NaOH soluble	7.14 per cent NaOH soluble	Copper number	Lignin	Cellulose	Alpha cellulose	Beta cellulose	Gamma cellulose	Pentosan	Methyl pentosan	Ash.
		<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>		<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
VA	Sound spruce, average-----	2.2	3.8	1.2	8.8	18.9	4.1	28.3	58.5	63.5	10.4	26.1	11.8	1.8	0.17
2556	Deadhead-----	1.4	1.3	0.5	12.0	19.7	5.9	30.9	59.5	60.0	16.1	23.9	9.8	2.8	.45
2549	Very slightly decayed-----	3.4	5.6	1.5	15.0	24.0	5.5	30.6	54.6						.38
2545	Slightly decayed, top of pile, mill run-----	4.1	6.3	1.7	20.6	28.5	7.7	30.5	54.1	42.8	37.7	19.5	11.3	1.6	1.37
2546	Considerably decayed-----	5.5	9.7	1.3	39.9	49.2	17.4	35.2	46.9	27.8	61.4	10.8	9.4	2.6	.75
2541	Badly decayed-----	6.5	11.9	1.4	50.2	62.3	23.5	38.2	42.0	17.0	74.6	8.4	8.5	3.7	.61

The deadhead log, No. 2556, contained a larger proportion of cellulose than did the sound wood. This condition is at least partially accounted for by the fact that it had been stored under water and the water-soluble material had been more completely removed. If the cellulose content of both samples be calculated on the basis of the residue after the removal of the hot-water-soluble portion, No. 2556 gives a slightly lower value than VA. In any event, the conclusion may be drawn that the log stored under water, and therefore out of contact with the air, had not suffered appreciable decay.

The stability of the cellulose isolated by the Cross and Bevan method is greatly decreased as measured by the resistance to the action of 17.5 per cent NaOH. This resistance is indicated by the proportions of alpha, beta, and gamma cellulose.

Both the cold-water-soluble and the hot-water-soluble content of these woods increased with increase in decay.

An even greater indication of increasing decay is afforded by the increase in solubility of the wood in caustic soda. The results obtained with 7.14 per cent NaOH appear to differ from those obtained with 1 per cent NaOH only in intensity. Even in wood which has not reached a sufficiently advanced stage of decay to be rejected for pulping, the solubility in 1 per cent NaOH has risen to 39.9 per cent, as compared with 8.8 per cent for sound wood. The copper number also increases with increased decay, but its changes during the earlier stages are not so pronounced.

The process of decay does not appear to have destroyed the lignin. In fact, the proportion of lignin increased as decay advanced. This increase can readily be explained, however, without assuming the formation of lignin, provided it is assumed that an actual loss in weight of wood substance occurs during decay. In this way the lignin, unchanged in weight, represents a larger and larger proportion of the residual wood. The decrease in wood density, already referred to, and the action of isolated fungi, described later, fully substantiate the assumption.

Pentosans showed a decrease and methyl pentosans an increase; but the significance of these changes is not yet clear.

The resins, as determined by solubility in ether, and the mineral content, as determined by the ash, were not appreciably affected by the process of decay.

ANALYSES OF MECHANICAL PULPS MADE FROM SOUND AND FROM DECAYED SPRUCE WOODS

Mechanical pulps Nos. 1AA and 2AB, ground respectively from sound wood No. 1 and decayed wood No. 2546, were chemically analyzed. The data are found in Table 8. The data for pulp No. 1AA, Table 8, closely resemble those for sound wood VA in Table 7. The small difference becomes even less significant when note is taken of the low water solubility of the pulp, due to the removal of a large proportion of the water-soluble content during the pulping process. On the other hand, in a comparison of the respective data for pulp No. 2AB and wood No. 2546, the decrease in water solubility is not sufficient to account for the more significant decrease in copper number, lignin, and solubility in NaOH, and for the increase in cellulose content. *If account is taken, however, of the brashness and brittleness of the decayed wood and of the abnormal losses in the white water, it*

may be assumed that the grinding process pulverized to a large extent the portion of wood which had suffered decay, and that after the removal of this finely divided matter, as well as the water-soluble products, the residual pulps had more nearly the properties of pulp made from sound wood.

TABLE 8.—Analyses of spruce groundwood pulp

Sample No.	Description	Cold-water soluble	Hot-water soluble	Ether soluble	1 p. ct. NaOH soluble	7.14 p. ct. NaOH soluble	Copper number	Lignin.	Cellulose.	Alpha cellulose	Beta cellulose	Gamma cellulose	Pentosan	Methyl pentosan
1AA	From sound wood No. 1.	P. ct. 0.0	P. ct. 1.0	P. ct. 0.4	P. ct. 10.1	P. ct. 18.3	4.4	P. ct. 29.7	P. ct. 60.0	P. ct. 60.5	P. ct. 24.5	P. ct. 15.0	P. ct. 11.9	P. ct. 2.0
2AB	From decayed wood No. 2546.....	.6	1.4	.8	17.7	27.4	6.6	29.7	59.6	58.7	20.7	20.6	10.3	2.6

HEMLOCK, BALSAM, AND ASPEN WOODS

Chemical analysis was made of sound and decayed hemlock woods, Nos. 2554 and 2542, and of decayed aspen wood, No. 2552, all previously described in connection with the pulping tests. A sample of aspen, No. 2551, freshly cut at Madison, Wis., was analyzed as representative of sound wood. Sound balsam wood, No. 2550, from Minnesota, and decayed balsam wood, No. 2553, from Wisconsin, were also analyzed.

The results are shown in Table 9. That none of these cases had reached a very advanced stage of decay is substantiated by the relatively small difference between the data for the sound and the affected material. Further substantiation is found in the results of the chemical pulping tests of the hemlock, already described, in which very little difference appeared in the yields obtained from the two stakes of this wood. (See Tables 3 and 4.) The effect of decay is evidenced by increased solubility in water and in NaOH, and by decreased stability of the cellulose as measured by the alpha, beta, and gamma cellulose. Mechanically, it is reflected in the decreased strength of both the soda and the sulphite pulps. In the case of the sound aspen, since the material that was pulped (see Table 3) was not the same as that analyzed, the pulping and analytical data are not directly comparable. The similarity of the analytical data for the two states of the wood suggests, however, that decay had not reached an advanced stage in No. 2552.

TABLE 9.—Chemical data on sound and decayed hemlock, aspen, and balsam

Sample No.	Description	Cold-water soluble	Hot-water soluble	Ether soluble	1 p. ct. NaOH soluble	7.14 p. ct. NaOH soluble	Copper number	Lignin	Cellulose	Alpha cellulose	Beta cellulose	Gamma cellulose	Pentosan	Methyl pentosan	Ash
2554	Sound hemlock.....	P. ct. 2.9	P. ct. 4.1	P. ct. 0.5	P. ct. 14.5	P. ct. 21.6	7.3	P. ct. 35.8	P. ct. 50.6	P. ct. 57.6	P. ct. 24.4	P. ct. 18.0	P. ct. 9.0	P. ct. 2.7	P. ct. 0.7
2542	Decayed hemlock.....	4.8	6.0	.7	20.2	29.0	8.2	31.0	53.4	51.8	29.2	19.0	6.7	6.6	.8
2551	Sound aspen.....	2.6	3.5	2.1	20.8	33.9	4.8	26.6	57.5	59.3	23.3	18.4	18.9	.2	.8
2552	Decayed aspen.....	3.4	4.7	1.7	24.1	32.7	5.8	26.3	55.9	55.6	28.6	15.9	18.3	.0	1.0
2550	Sound balsam.....	.5	1.3	1.0	10.1	18.0	6.1	31.5	50.5	58.5	18.0	23.5	10.2	2.4	.4
2553	Decayed balsam.....	6.5	9.4	.7	22.8	30.6	8.3	30.5	52.8	54.8	27.4	17.8	9.1	2.6	1.2

Sound and decayed balsam Nos. 2550 and 2553 were selected at random from mill piles. Like the hemlock, the balsam showed a higher cellulose content in the decayed material than in the sound. The true evidence of decay is seen, however, in the increase in copper number and solubility in water and in NaOH, and in decreased stability of the cellulose. Unfortunately, it was not practicable to make pulping trials on the balsam woods.

SPRUCE SULPHITE PULP

Spruce sulphite pulps Nos. 2547, 560, 2548, and 2555, prepared from woods containing successively increasing amounts of decay, were chemically analyzed, with results as shown in Table 10. The data as to cooking and physical properties of these pulps are those previously given in Table 3. The chemical data for pulp No. 2561 are taken from records of work done previous to these studies, and are representative of pulp made from sound spruce.

TABLE 10.—Analyses of sulphite pulps from spruce woods

Sample No.	Description	Cold-water solu- ble		Hot-water solu- ble		Ether soluble		1 p. ct. NaOH soluble		7.14 p. ct. NaOH soluble		Copper number	Lignin		Cellulose		Alpha cellulose		Beta cellulose		Gamma cellu- lose		Pentosan		Methyl pento- san		Ash
		P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct		P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	P.ct	
2561	From typical sound wood.....	0.1	0.0	1.1	11.0	20.5	3.0	1.2	97.2	87.5	3.2	9.3	3.5	0.8	0.29												
2547	From slightly decayed wood No. 2545.....	.0	.0	1.5	10.8	24.8	2.6	2.8	96.1	75.8	17.9	6.3	4.6	.6	.57												
560	From somewhat decayed wood No. 2560.....	.3	.0	1.3	14.3	28.2	3.8	1.5	96.5	79.4	11.4	9.2	4.2	.9	.33												
2548	From considerably decayed wood No. 2546.....	.0	.0	1.0	13.4	31.3	3.7	2.1	96.1	73.0	22.0	5.0	3.6	1.4	.50												
2555	From badly decayed wood No. 2541.....	.3	5.0	.9	31.9	52.8	9.0	1.7	94.4	46.1	48.6	5.3	2.9	1.4	.81												

The pulps did not vary greatly in purity. None, with the exception of No. 2555, contained less than 96.1 per cent cellulose, and none more than 2.8 per cent lignin. The progressively increased degree of decay in the woods was clearly reflected in the pulps, however, by the increase in their solubility in NaOH and the decrease in stability of the cellulose. The copper number did not show any marked increase, except in the one case of advanced decay.

SPRUCE SODA PULP

Soda pulps Nos. 2559 and 2557, prepared, respectively, from slightly and badly decayed spruce, the same lots from which were made sulphite pulps Nos. 560 and 2555 (Table 10), were analyzed, and the data are given in Table 11.

The low cellulose and high lignin in pulp No. 2557 indicate clearly its undercooked condition, which was evidenced also by the large proportion of screenings, 16.8 per cent, and by the weak, brittle condition of the screened pulp. It is not surprising to note, therefore, that this pulp was still soluble in alkali to a considerable degree. Pulp No. 2559 also appears far from pure, containing as it does 9.6 per cent lignin and only 89.4 per cent cellulose.

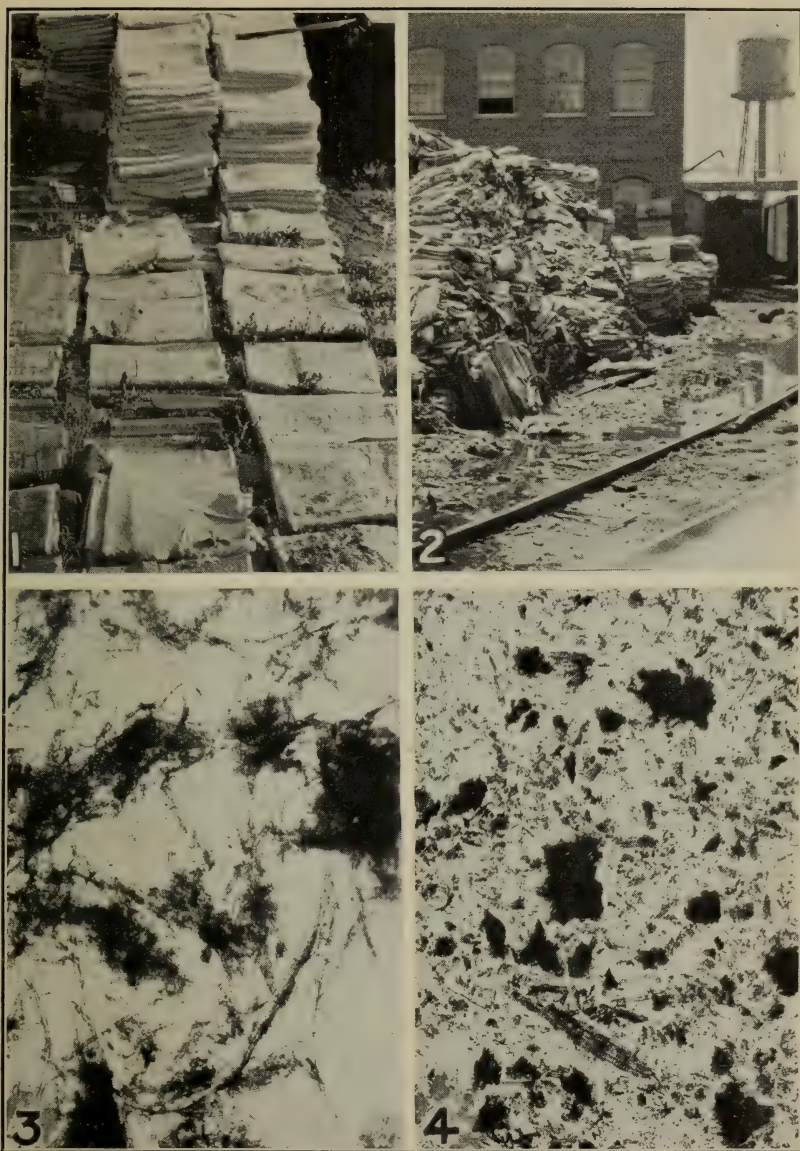


FIG. 1.—Ground-wood pulp stored in a wood yard on low swampy ground supporting a dense growth of grass and weeds. Sawmill slabs are used for a base. This is extremely poor practice. Conditions probably could not be worse for decay at the bottom of the piles.

FIG. 2.—Pile of ground-wood pulp on swampy ground. Note the surface water all about the pile. This yard should have been drained and surfaced with cinders before use for storage purposes.

FIG. 3.—Fibers of sound ground-wood pulp.

FIG. 4.—Fibers of decayed ground-wood pulp. Note how the fibers have been broken up into short fragments through the action of wood-destroying fungi.

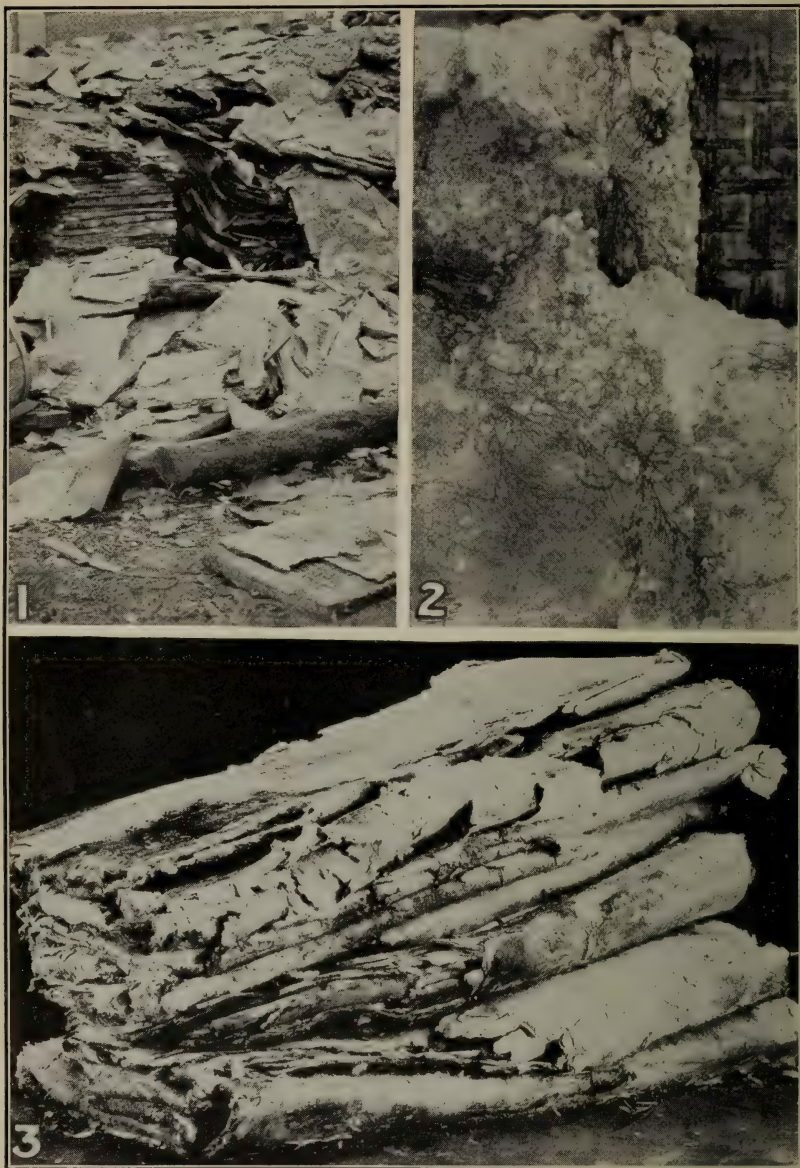


FIG. 1.—Base of a pile of Canadian hydraulic-pressed ground-wood pulp worthless from decay after three years' storage on an open platform. The pile was originally 20 feet high and contained 7,500 tons. More than \$10,000 worth of this pulp was an absolute loss

FIG. 2.—Lap taken from near the base of the pile shown in fig. 1, showing brown strand-like mycelium of a fungus

FIG. 3.—Several laps of ground-wood pulp deteriorated by wood-destroying fungi during a six months' storage period in a mill basement

In view of the incompleteness of the alkaline pulping action, it is doubtful whether the chemical data for these pulps has much significance with regard to decay in the wood.

TABLE 11.—*Analyses of spruce soda pulps*

Sample No.	Description	Cold-water soluble	Hot-water soluble	Ether soluble	1 p.ct. NaOH soluble	7.14 per cent NaOH solub.	Copper number	Lignin	Cellulose	Alpha cellulose	Beta cellulose	Gamma cellulose	Pentosan	Methyl pentosan	Ash
2559	From slightly decayed spruce No. 2560 ¹	P.ct 0.8	P.ct 0.2	P.ct 1.0	P.ct 3.2	P.ct 6.6	2.6	P.ct 9.6	P.ct 89.4	P.ct 57.1	P.ct 39.1	P.ct 3.8	P.ct 7.8	P.ct 0.7	P.ct 1.17
2557	From badly decayed spruce No. 2541	.6	.0	.7	7.0	13.6	7.9	38.3	56.4	23.3	69.7	7.0	4.5	2.7	2.08

¹ Decayed spruce wood, sample No. 2560, was not analyzed, but was comparable to spruce No. 2545. (See Table 7.)

GENERAL DISCUSSION OF CHEMICAL DATA

Even the limited amount of data obtained in this study clearly indicates the value of chemical analysis as an aid in studying the progress of decay and its effect upon yield and quality of pulp. The analytical tests which seem to offer the greatest promise in this direction are tests for cellulose content and for solubility in water and in 1 per cent NaOH, together with possible determinations of alpha, beta, and gamma cellulose. It is not unlikely that a quantitative relation between some or all of these values and the degree of decay, as evidenced by the pulping value of the wood, can be worked out for the different species. A qualitative parallelism at least, has been clearly demonstrated for spruce woods, and this persists in the mechanical and sulphite pulps made from them. The tests for solubility in hot water and, especially, in 1 per cent NaOH are easy to apply, and ought to prove correspondingly valuable. The determination of total cellulose content, and of alpha, beta, and gamma cellulose, are more difficult operations, and are not likely to afford much information beyond confirmation of the results indicated by the solubility tests. Furthermore, relatively small amounts of decay appear to be reflected with greater definiteness by the solubility in alkali than by any of the other tests.

STORAGE OF PULP

Chemical pulps, as a rule, are stored indoors. Ground wood, on the other hand, is often stored in the open in large, compact piles up to 20 or 30 feet high (Pl. X, fig. 1). It is also stored in unheated closed sheds, or in the warm basements of the mills. It contains about 70 per cent moisture as it comes from the wet machines. Occasionally it is piled on concrete bases; more often it is piled on planks or slabs (Pl. X, fig. 2) which are commonly infected with wood-destroying fungi and ready to transmit the infection to the stock. (See Pl. X, fig. 3.) In some cases it is piled directly on the ground, or on older, sometimes badly infected, pulp. (See Pl. X, fig. 4.) For lack of suitable storage space, piles are often placed on low, swampy ground amid a luxuriant growth of grass and weeds. (See Pl. XI, fig. 1.) In some instances piles are placed in poorly

kept wood yards (Pl. XI, fig. 2) surrounded by rotting débris and subject to abundant infection from fungi.

Storage in unheated sheds, which naturally affords protection against weathering and soot, and partial protection against airborne spore infections, probably does not protect against deterioration by fungi after infection has actually taken place. Where pulp is preserved with a volatile antiseptic, a closed building would be of advantage in retaining the vapors.

Pulp piled in warm, moist basements will be especially subject to deterioration, and it should not be held under such conditions longer than is absolutely necessary.

LENGTH OF STORAGE

Because of manufacturing conditions, a rather long storage period is in many cases necessary for ground wood pulp. A large volume of this pulp is ground by hydroelectric power, the supply of which is dependent on stream flow. Thus, at many mills, production becomes seasonal and must be concentrated at favorable times; and storage of large quantities of material, for both local consumption and shipment, becomes necessary over periods of from 6 to 12 months or even longer.

Chemical pulps are for the greater part converted into paper immediately, or within a few months.

DETERIORATION DURING STORAGE

Molds and wood-destroying fungi are the chief enemies of pulp. Molds cause physical deterioration by (1) discoloring the pulp, and (2) binding together the particles so that the molded spots or areas do not beat up well—a lumpy, speckled paper resulting. Wood-destroying fungi decrease the strength of the wood fibers and make them so brittle that they break into short lengths (Pl. XI, figs. 3 and 4) in the beater, with the result that much of the pulp is lost in the white water and the manufactured paper has little strength. The combined action of molds and wood-destroying fungi results in the production of paper of a very poor color and quality.

The losses during the storage of pulp may be large. They depend upon the length of the storage period and the conditions under which the pulp is stored.

Chemical pulps, in ordinary commercial practice, deteriorate much less than do ground-wood pulps, owing to their shorter storage period and the complete sterilization which takes place during the process of cooking. Molds, however, which are more likely to develop than decay organisms, may cause more or less trouble in the manufacture of the better grades of paper; and in extended periods and poor conditions of storage both decay and molding may become just as severe in chemical pulps as in ground wood. For a further discussion see Blair (6).

A rather common belief among pulp manufacturers is that the more sulphite liquor the pulp retains the more rapid will the pulp deteriorate during storage. A few tests were conducted at the laboratory in an attempt to find out something on this point. While not conclusive, the tests at least indicated that traces of sulphite liquor remaining in the pulp do not hasten the deterioration caused by fungi.

The writers have had very little opportunity to observe deterioration in hydraulic-pressed ground wood, but the information at hand indicates that pulp so treated will not offer any greater resistance to decay than the wetter laps. This is to be expected, as the pressed pulp still contains 40 to 55 per cent moisture. The case already cited of a total loss in a portion of a 7,500-ton pile (Pl. XII, figs. 1 and 2) after storage for somewhat less than three years is strong evidence on this point.

Several writers have expressed opinions as to the sources of fungous infection in fresh pulp. Some hold that infection in the wood carries over through the grinding process and continues to develop in the pulp. Acree (1), Beadle and Stevens (4) (with reference to blue stain caused by *Ceratostomella* spp.), and Klemm (14) have expressed themselves as inclining to this view. Blair (5) likewise states:

The process of manufacture does not affect the fungus in any way except to separate it into a great number of small pieces which are distributed throughout the pulp. When such pulp is stored, each piece of the fungus may set up a center of decay within the pile whether of laps or of bales.

Sée (23), in discussing the molds that injure paper, remarks that—the germs of these true maladies of paper are not caused by any sort of later infection, but preexist in the pulp from which the paper is made, and probably proceed from the materials used in making paper pulp, such as straw, alfalfa fiber, etc.

In order to find out whether the infection in ground wood originates in the decayed wood used in its manufacture, an experiment was conducted, the material used being pulp freshly ground from decayed spruce at one of the cooperating mills.

The wood used was abundantly infected with *Fomes roseus*, *Lenzites sepiaria*, *Polystictus abietinus*, *Stereum sanguinolentum*, and *Trametes pini*.

The rots were not so far advanced but that the mycelium of each of them should have been alive in all cases. Culture tests proved this to be true, for *Fomes roseus* and *Stereum sanguinolentum* at any rate. Samples of the ground wood were collected in sterile bottles as the pulp left the grinder. A number of samples from freshly ground, commercially sound wood were also collected. The temperature at the discharge varied from 120 to 180° F. (49 to 82° C.). At the surface of the stone, however, the temperature was much higher, and it should be noted that very minute particles of the fungus were for a short time exposed to this heat.

None of the samples, either from commercially sound or from decayed wood, produced a single wood-destroying fungus when plated out into Petri dishes on malt agar. Some plates remained sterile, but the remainder were overrun with molds, such as *Trichoderma* spp., normally obtained from river water. As many plates were sterile among those representing the infected wood as there were among those representing the sound wood. No difference could be observed in the species of molds obtained on the two groups of plates, a condition which would indicate that water, and perhaps air, are the sources of infection.

Considerable amounts of each sample were planted upon sterilized clean ground-wood pulp (approximately 70 per cent wet) supported

over water in fruit jars. These cultures were kept for more than a year in an inside basement room in which the temperature was fairly constant (19 to 24° C.). In no case did infection by wood-destroying fungi occur. The remaining amounts of the samples were kept in the original containers, which were capped with cotton and cloth. After 14 months no evidence of hymenomycete infection had appeared, although most of the samples were infected with one or two species of molds.

This experiment is at least an indication that no infection from the rotten wood is carried through the grinding process. Undeniably, pulp made from infected wood does deteriorate faster in storage than that made from sound wood. (See Table 12.) This tendency would seem to be due to an increased susceptibility to infection rather than the bodily transfer of fragments of fungi from the wood.

Woody or other organic materials infected with living fungi are, however, a common source of infection—a fact which is particularly noticeable with decay-producing fungi. Barnes (2) placed rotten pulp in sound pulp and incubated the bundles for several weeks. The results led him to believe that the infection would not be transmitted. This opinion is not supported by repeated observations of what actually takes place in commercial storage. Pulp may become infected not only by contact with infected pulp but also by contact with other decayed materials. Rotten wood floors in storage sheds and plank bases for pulp piles frequently infect pulp placed in contact with them, and the infection may pass upward through a considerable number of laps. Any infected wood placed within or in contact with a pile may spread decay. An interesting demonstration of such contagion occurred in one of the experimental piles, where certain planks picked up about the yard were used to separate the experimental material from surrounding mill stock. At the end of six months an infection with a wood-destroying fungus could be traced from the planks downward through as many as eight laps.

The dirt carried on workmen's shoes and clothing is also a likely source of infection. The soil about pulp mills is loaded with fungi, and even small quantities transplanted to fresh, moist pulp are bound to start infections, each of which may eventually involve several hundred pounds of pulp. For this reason it would be highly advisable for each workman handling pulp to keep a pair of clean shoes for use on the pile only, and never to wear them anywhere else. Upon attention to just such details, to the layman apparently of little import, have been built up the highly successful practices of modern medical sanitation.

There still remain two other possible sources of infection to be considered: Contaminated water used in the manufacturing processes, and fungous spores carried by the air.

Beadle and Stevens (4) hold that little infection comes from the water. They advance the idea that infection depends upon the food-yielding capacity of the wood, which varies with the season of cutting; that in the spring and summer the wood contains, in the pith rays, sugars and other organic food materials which are favorable to mold growth; that in the fall these foodstuffs are converted into insoluble reserve substances, such as starch, which are less available as food for fungi; and that the only part water plays in the contamination

of ground-wood pulp, aside, of course, from furnishing the requisite moisture, is in its reaction upon the foodstuffs in the wood, rendering the organic substances more or less available for the growth of fungi according to its softness or hardness. They also attribute to the mineral and nitrogenous substances in the water the possible function of nourishing the molds in their early development.

Barnes (2), on the other hand, points out the necessity of keeping pulp out of contact with pools of water, because "the more impurities an organic body contains, the greater tendency there is for that body to decay." Sée (23) maintains that water used in manufacture is at least one source of infection, and in this Wolesky (27) concurs. Sée also remarks that in considering the molding of paper the sizing should be viewed with suspicion.

After examining a large number of laps of pulp one becomes impressed with the fact that much of the infection is internal; that is, that many of the infected spots or areas originate within the laps. The decay has apparently been introduced through the water or through the air. Since many of the molds and two of the wood-destroying fungi commonly found on pulp have been isolated from river water used for manufacturing pulp, the inference is drawn that water probably plays a considerable part in infection.

Air-borne infections must also play their part. All of the fungi produce spores that are more easily carried about by air currents than the finest dust. In the case of the wood destroyers not only do the fruit bodies produce an abundance of spores, but in some cases the mycelium may also develop them. The mature spores germinate readily on any moist surface; if they happen to fall on pulp they are likely to start new infections which may spread rapidly. For this reason, rotting wood or pulp should not be left in close proximity to new pulp piles. As for mold spores, they are everywhere in the air (6) but of course are more abundant where there are large amounts of organic matter in a state of partial decomposition.

To prevent deterioration in stored pulp from the action of fungi and bacteria, then, the sources of infection should be eliminated so far as possible. Wood foundations for piles should be replaced with concrete or antiseptically treated lumber. The yards or sheds should be cleaned of infecting débris. Workmen should use care to keep infecting materials out of the piles. The water used in manufacturing processes should be filtered and sterilized if possible. These precautions will all aid in maintaining the pulp in good condition, but for complete protection it will also probably be necessary to introduce an antiseptic into the pulp itself.

PHYSICAL PROPERTIES OF PULP DECAYED IN STORAGE

In order to demonstrate the deterioration in the quality of mechanical pulps due to decay during storage, an experimental study of commercial pulps was made. One lot was stored at the mill and all the others at the Forest Products Laboratory.

The investigation began with two shipments of approximately 1,000 pounds each, designated A and B, from one of the cooperating mills. Shipment A had decayed during six months' storage (Pl. XII, fig. 3 and Pl. XVIII). Shipment B, submitted for comparison, con-

sisted of freshly ground pulp. The cooperator described these pulps as follows:

One lot is freshly ground pulp from approximately 70 per cent spruce and 30 per cent balsam, ground at close to 70 horsepower with a 10-cut, screw-thread burr, at 160° F. The other pulp is of similar wood and similar grinding, except that it was stored for six months in a dark, high basement where it quickly became infected, as the laps show.

The decayed pulp was found to be very free, brash, and brittle, and in some of the badly decayed areas could be crumbled to a dust by rubbing between the fingers. The fiber length averaged 0.25 millimeters, as compared with 1.09 millimeters for the freshly ground pulp. (See Pl. XI, figs. 3 and 4.) Under as nearly identical beater and machine conditions as possible, both pulps, without the admixture of other fibers, were run into waterleaf paper on the laboratory machine. The decayed pulp ran much freer and also showed a tendency to stick to the couch and press rolls. It foamed badly, and this trouble was not overcome even with the addition of 2 per cent size and 2.5 per cent alum. Owing to the excessive amount of fine fiber, approximately 8.5 per cent more of the decayed than the sound pulp was lost in the white water.

The paper made from the decayed pulp was considerably darker than that from the fresh pulp. The difference, evident to the eye, was also clearly indicated by color readings on the Ives tint photometer, which gave for the decayed pulp 50.5 per cent white and 39.5 per cent black, and for the good pulp 60.5 per cent white and 23 per cent black. The paper from decayed pulp was much the dirtier, containing 20 times as many specks per unit area as the other. It possessed less than half the bursting strength and only about half the tensile strength, and was only one-tenth as resistant to ink penetration as the paper made from sound pulp.

Tests were then made, under more carefully controlled conditions, (1) to check the results obtained on pulps from shipments A and B, and (2) to determine the relative resistance of pulps made from sound and from decayed wood to decay in storage. Pulps in the form of commercial laps were stored at the Forest Products Laboratory in a room in which were maintained a high relative humidity and a temperature suited to the development of fungi.

A number of the laps were selected from pulps freshly ground from sound and from decayed spruce, data for which have been given in Table 2. They were designated as pulp No. 1AA, made from sound wood No. 1, and pulp No. 2AB, made from decayed wood No. 2546. Other laps were selected from a shipment of hydraulic-pressed pulp, No. 3AC, received from a Wisconsin mill. This material was in reasonably sound condition at the time the tests began; otherwise its history is not known. All the pulps were stored in the humidity room for a period of 12 months. In the same room during this period were stored 4,000 small laps of mechanical pulp which had been sprayed with disinfectants and inoculated with various molds and wood-destroying fungi, and also a large amount of badly decayed hydraulic-pressed pulp as a source of infection for the three pulps under observation. There was ample opportunity, therefore, for these to become thoroughly infected, as they did, during the test period.

At the end of approximately six months, and again at about the end of the year, some of the laps of each of the three pulps, so selected as to be as representative as possible of the state of decay throughout the lot, were made into waterleaf paper on the laboratory machine without the addition of other fibers.

The hydraulic pulp, and especially the pulp made from decayed wood, foamed very badly on the screen and paper machine. The pulp made from sound wood did not. Trouble on this account increased with the age of the pulp.

The papers from all three sources showed during storage an increase in freeness, a progressive darkening and yellowing, a loss in strength, and a decrease in the average length of the fibers.

The experimental data are given in Table 12. The color change, as measured by the Ives tint photometer, is indicated by a decrease in the percentage white and an increase in the percentage red plus green (yellow). The change was much more rapid in the samples from decayed wood. The bursting strength and the tensile strength in all cases showed a decided decrease, this effect being more rapid for the samples from decayed wood. The rate of weakening was higher during the first than during the second six months, a result which is in accord with the microscopical and chemical observations on these samples.

There was a marked difference in the amount of dirt and specks in the papers, those made from sound wood pulp being much cleaner.

TABLE 12.—Physical properties of ground-wood pulps

Sample No.	Description	Green sedimentation test. Over-flow	Color (tint photometer)			Average length of fiber particles	Strength factors at 65 per cent humidity			
			White	Black	Red plus green		Weight of ream 24 by 36—500	Points per pound	Average breaking length	Average stretch
1AA	From sound spruce:	Cc.	Per cent	Per cent	Per cent	Mm.	Pounds		Meters	Per cent
1AA ₁	Freshly ground	91	68.5	20.0	11.5	1.5	47.0	0.30	2,780	1.4
1AA ₁	After 6 months	100	67.5	19.8	12.7	.9	49.8	.27	2,340	.8
1AA ₂	After 12 months	180	64.6	22.8	12.6	1.0	46.0	.22	2,175	1.3
2AB	From decayed spruce:									
2AB	Freshly ground	100	62.5	27.5	10.0	1.4	48.0	.30	2,610	1.3
2AB ₁	After 6 months	141	56.6	29.3	14.1	1.0	51.9	.21	1,990	.6
2AB ₂	After 12 months	160	54.0	27.4	18.6	.7	47.0	.19	1,780	1.2
3AC	Hydraulic pressed pulp:									
3AC	Freshly ground									
3AC ₁	After 6 months	132	66.0	23.3	10.7	1.1	46.0	.22	1,910	.6
3AC ₂	After 12 months	170	59.8	26.0	14.2	1.0	47.0	.20	1,905	1.2

PRESERVATION OF PULP BY CHEMICAL TREATMENT

The chemical treatment of pulp is the most reliable method of preventing deterioration during storage, although to a considerable extent decay may be reduced by the methods of storage already recommended in this bulletin. Molding of pulp, however, appears to be more difficult to control than decay. Moist pulp, particularly ground wood, will prove highly susceptible to the attack of fungi (so long as the temperature is favorable to the growth of these organisms) unless their food supply is poisoned by the introduction of antiseptics.

If it were commercially feasible always to dry the pulp below the limits required for fungous growth, say to from 15 to 20 per cent, or, on the other hand, to keep it completely saturated, the problem would be largely solved. (See Blair and Parke-Cameron (7) for a discussion of under-water storage for mechanical pulp.)

WORK OF OTHER INVESTIGATORS

The writers are aware of only one reference in literature to attempts earlier than their own to preserve pulp from decay by the addition of antiseptics. This is a brief mention by Wolesky (27) of preliminary tests, from which he concludes that 0.25 per cent solutions of sodium chloride, magnesium sulphate, or aluminum sulphate applied on the wet machine would protect ground wood.

Concurrently with the present investigation, Bates (3) has discussed tests made at the Kenogami mill of Price Brothers & Co. (Ltd.), of Canada. This investigator reports spraying approximately 29 tons of wet pulp with three chemicals—zinc chloride, mercuric chloride, and sodium fluoride. The chemicals were applied as a water solution by means of a perforated brass pipe, which delivered about 5 pounds of solution per minute on a felt roll fitted to the top press roll. Zinc chloride was used in a 3 and a 7.15 per cent concentration, mercuric chloride in a 0.107 and a 0.428 per cent solution, and sodium fluoride in a 1.14 and a 2.86 per cent solution. Some solution was necessarily pressed out and lost in the white water.

After treatment most of the material was piled in a storage shed. For the first eight months it lay in separate exposed piles at one end of the building, in a cool location, and showed little change. Later the piles were transferred to the middle of the building and buried under the season's supply of pulp. After 12 months they were again inspected. In no case, even in the adjacent untreated pulp, was deterioration serious.

At the time the material was put into the storage shed about 20 laps treated with each preservative, together with 20 untreated laps for each, were placed in a closed, humid kiln of brick construction in the mill basement, where conditions for decay were very much more favorable. After 18 months this material was in a condition far different from that of the material placed in the shed. The laps with the light and the heavy zinc chloride treatments were badly discolored by black fungous spots scattered throughout the pulp, the effect being worse in the case of the heavier chemical treatment. Those treated with mercuric chloride, both light and heavy, were also badly discolored with green and gray mold patches, although the pulp was fairly well preserved from decay. Those from the sodium fluoride solution, however, were in strikingly good condition as compared with the untreated pulp, which was seriously molded and rotted. These tests pointed to the conclusion that sodium fluoride in 1.14 per cent concentration, applied at the rate of about 12 pounds per ton of air-dry pulp, or 4 pounds per ton of wet pulp having a moisture content of 72.7 per cent, probably may be used very effectively as a preservative for ground wood.

EXPERIMENTAL PROCEDURE

TESTS AT FOREST PRODUCTS LABORATORY

During the course of this study, 112 different chemical preservatives were investigated, with the object of finding an efficient one that could be applied to pulp at a reasonable cost.

About 3,000 small ground-wood laps and 1,400 sulphite laps were treated and tested under laboratory conditions, in addition to ground-wood pulp experimentally treated in the two mill tests described in the following section.

Laboratory procedure was in general, as follows: On a small wet machine there were run off laps of fresh pulp about 25 inches long, 12 to 14 inches wide, and one-eighth inch thick. After the laps had been trimmed to about 21 inches in length they were separated into bundles of 7 and 3. Each bundle was then weighed separately, and all 10 laps were afterwards spread out on a table and sprayed on both sides with preservative by means of an ordinary hand-operated 2½-gallon compressed-air garden sprayer.

Moisture determinations showed the ground-wood and sulphite laps to be about 30 and 25 per cent oven-dry, respectively, before spraying. Each piece of the lot containing seven laps was then inoculated by shaking on one surface from an atomizer bottle a heavy water suspension of the mixed spores of 25 molds. The three other laps were each inoculated in 10 places with mycelial cultures of five wood-destroying fungi grown on agar, small squares of the agar being cut out with the growing fungus. After inoculation each lot of seven and of three was folded once and then weighed for the second time in order to determine the amount of preservative in the pulp, the weight of inoculating substance being negligible.

The amount of pulp treated at the laboratory varied from 3 to 15 pounds, oven-dry weight, for each concentration applied. The concentration of solution used was to a certain extent limited by the solubility of the chemical; but where the antiseptic value was doubtful and the substance easily water-soluble in the desired amount, 5 per cent solutions were chosen for the preliminary tests. In later tests of substances which looked promising the concentrations, and hence the amount of antiseptic per unit of pulp, were in many cases reduced.

At the end of a day's run the bundles of laps were taken to a storage house (Pl. XIII, fig. 1) in which the air was kept highly humid and the temperature held at 72 to 75° F. The bundles of seven laps inoculated with molds were for the first few months stacked closely on narrow shelves, with one or more untreated laps separating the treated bundles, and with occasional bundles of untreated test laps interspersed at random to serve as checks or blanks. For the last 10 months of the test, however, the bundles were repiled with thick laps of very rotten hydraulic-pressed pulp separating the layers, so as to give a more severe infection. The bundles of three laps, inoculated only with wood-destroying fungi, were piled on other shelves and separated only by laps of clean, untreated pulp.

The increase of moisture content due to treatment varied, of course, with the amount of solution applied, but no records of this were taken at the time of spraying.

Very little drying seems to have occurred during storage, except in the case of a few laps at the top of the piles before they were inter-piled with the decayed commercial ground wood. The average moisture for the 81 representative laps sampled at the time of the last inspection was approximately 71 per cent, varying for the individual specimens between 41 and 81. There were only 17 laps below 65 per cent, and 64 between 65 and 80 per cent.

COMMERCIAL TESTS AT MILL

Preservative tests, made at two Wisconsin mills, involved approximately 2,900 and 4,300 pounds of ground-wood pulp. In both cases the preservative was sprayed on the pulp on the wet machine. The results of the tests are recorded in Table 13.

Test A.—At one of the mills 18 preservatives that had appeared promising in earlier laboratory tests were used in varying concentrations with the object of checking them under mill conditions. Several of the substances were further diluted in order to determine the minimum quantity effective under commercial conditions.

The treating solutions flowed from a barrel set on a platform about 4 feet 6 inches above the suction box on the wet machine. The barrel was connected to a pipe which was perforated with holes three-sixty-fourths inch in diameter and one-half inch apart from center to center, the pipe extending along the stretch roll 2 inches above it. All pipes were copper. A strip of cloth 5 inches wide hung from the perforated pipe and brushed against the pulp. The perforations were turned upward about 45° from the horizontal, thus causing the chemical always to flow to the pulp by way of the cloth.

After treatment the commercial laps were piled in a moist basement under the wet-machine room and surrounded by the regular stock. (See Pl. XIII, fig. 2.) In computing the amount of chemical applied it is assumed that 70 per cent was retained in the pulp as it came from the wet machine. From 25 to 60 pounds of pulp, oven-dry weight, were treated with each concentration of preservative.

Test B.—This test at the second mill included five of the most promising preservatives: Boric acid, sodium borate (borax), sodium dichromate, sodium dinitrophenolate, and sodium fluoride. The solutions were made up in cold water, with the exception of borax and boric acid, which go into solution much more quickly in warm water.

The solutions, strained through fine wire mesh, were added to the pulp at the top press roll by dripping from a three-eighth-inch brass pipe perforated with one sixty-fourth-inch holes spaced three-fourths inch apart from center to center. This pipe extended the full width of the machine, and was connected with a clean 50-gallon barrel. There were two globe valves in the line for regulation of flow. The barrel was hung from the ceiling, so that the solution had a minimum head of 2 feet. It was slightly tilted to one side, and a clean-out hole provided. The rate of flow of the solution was adjusted as closely as possible by preliminary trials with the intention of setting the second valve at a fixed point and moving only the first, as a cut-off. In actual practice, however, it was found necessary to regulate the second valve from time to time, according to flow judged by the eye. The tendency of the small holes in the pipe to plug was not particularly

marked, and could be compensated for by slight adjustments and by occasional picking out. With entirely clear, carefully strained solutions probably no difficulty would be experienced.

From 125 to 250 pounds of pulp, oven-dry weight, were treated with each concentration of preservative. The amount of chemical applied was figured on the basis of 70 per cent retention. After treatment, the pulp, together with a quantity of untreated material, was piled in the basement of the mill for later observation.

RETENTION OF CHEMICAL ON WET MACHINE

The amount of chemical actually retained by pulp sprayed at the press rolls depends mainly on the pressure applied at the rolls. To obtain experimental data on this question several tests involving somewhat more than 200 pounds of wet pulp were conducted on the small wet machine at the laboratory. Sodium chloride (common salt) was the chemical used, for the reason that it can very easily be washed from pulp and quantitatively determined with silver nitrate.

The salt solution was dropped on the pulp at the press roll from a three-eighth-inch brass spray pipe having one sixty-fourth-inch perforations spaced three-fourths inch between centers. The speed of the sheet was 41.9 feet per minute. Every tenth lap, or approximately one lap every five minutes, was sampled for sodium chloride and moisture.

In the case of a 5 per cent solution, approximately 70 per cent of the dry weight of salt was retained by the pulp. With a 25 per cent solution, the retention was somewhat greater (74 per cent), as less of the solution had to be applied to leave equivalent quantities of dry salt in the pulp. In mill practice some of the chemical can be recovered by recirculation of the white water.

DIFFUSION OF CHEMICAL IN PULP

The rate and amount of diffusion of chemical in the pulp have an important bearing on the tests conducted and are of particular importance in determining the commercial method of applying preservatives on the wet machine. To get information on this point, a series of special tests with sodium chloride was begun.

Some of the ground-wood laps used in the sodium chloride retention tests were reserved for the purpose, and a number of fresh laps of ground wood were run off at a moisture content of 71 to 73 per cent.

In one set of tests 14 treated and 90 untreated laps were sprayed with filtered lake water in quantities as nearly as possible equal to those used in the regular preservative tests. The treated laps were gathered into 2 bundles of 7 and folded once; the untreated into 18 bundles of 5 and folded once, making 10 thicknesses to a bundle. A "sandwich" stack was then built up of 6 untreated bundles and 1 treated bundle alternately, 5 layers in all, each layer of treated pulp thus being faced with 60 thicknesses of untreated.

In a second set of tests, 28 treated and 50 untreated laps were taken. Their moisture contents ranged from 71 to 73 per cent, and it was decided not to add water. They were folded in the same sized bundles as the laps used in the first test and piled together, the treated bundles being laid between 20-fold thicknesses of untreated laps.

Quantitative analyses of laps from the first set were made after two weeks and again after two months. The treated pulp at the beginning of the experiment contained 1.16 pounds of salt per 100 pounds of wet pulp. At the end of two weeks salt from the uppermost treated bundle, after an upward penetration of 20 thicknesses, showed a concentration of 0.04 pound per 100 pounds of wet pulp; from the lowest treated bundle, downward diffusion had evidently reached the bottom (through 60 thicknesses), where a concentration of 0.01 pound per 100 pounds was indicated.

In two months the upward diffusion from the first treated bundle exceeded 33 laps, concentration reaching 0.03 pound per 100 pounds in the thirty-third. In the sixth lap from the bottom of the pile the concentration was 0.08 pound per 100 pounds.

In the drier pulp of the second test set, observations showed that diffusion was going on with a rapidity about equal to that in the first. No formal record was kept.

During the storage phase of the preservative experiments at the Forest Products Laboratory, diffusion undoubtedly accounted for a certain amount of mingling of chemicals as well as loss by penetration into untreated spacer laps, and the lower the laps were in the pile the greater the diffusion, owing to the greater pressure and closer contact of the bundles or layers. In the second mill test, however, diffusion did not affect the results, since pulps of different treatment were placed in separate piles.

As a matter of preservation, the rapid diffusion of a chemical through pulp is highly beneficial. From the facts observed it seems perfectly safe to conclude that any minor irregularity in the application of the antiseptic is quickly compensated for, and that uniformity of treatment is insured. Under manufacturing conditions in which every lap in the pile would be treated, loss from diffusion would not occur; and, therefore, smaller amounts of chemical than were found effective in the laboratory tests can be recommended for commercial practice.

RESULTS OF PRESERVATIVE TREATMENTS

Table 13 presents a record of preservative treatments applied both at the laboratory and at the mills. In its interpretation the footnotes will help to explain certain apparent discrepancies. The results of the mill tests, which followed commercial methods, must be the final check on the value of the antiseptic.

In each series of tests a number of untreated laps were interspersed in the piles to serve as checks. Their condition was noted at different inspections. Except in a few cases where the laps dried too much, the records indicate that these check laps were severely or completely molded and decayed at the time of the last inspection.

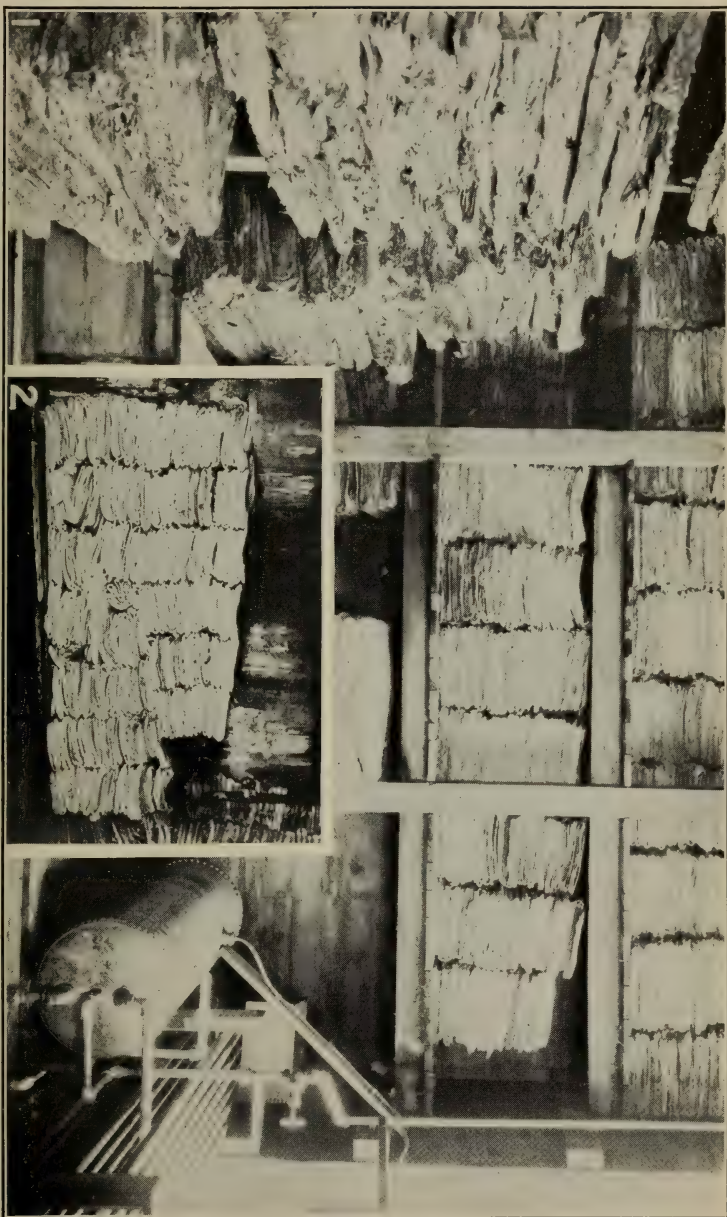


Fig. 1.—Humidity-controlled and temperature-controlled storage shed at the Forest Products Laboratory in which ground-wood and sulphite pulps sprayed with 106 different chemicals were kept under observation for nearly two years. The laps in the background are in bundles of three, each being inoculated with five different wood-destroying fungi. The experimental pulp on the left side of the shed was inoculated with a large number of molds. The large lapped are rotten hydraulic-pressed ground wood used to increase the infection. Between these are single layers of bundles, each bundle consisting of seven test lapped once.

Fig. 2.—Pile of commercial ground-wood lapped at a Wisconsin mill with 18 different preservatives and placed in a warm, moist basement. This experimental pulp was piled at one side against the wall and was surrounded on all other sides by the regular-run ground wood.

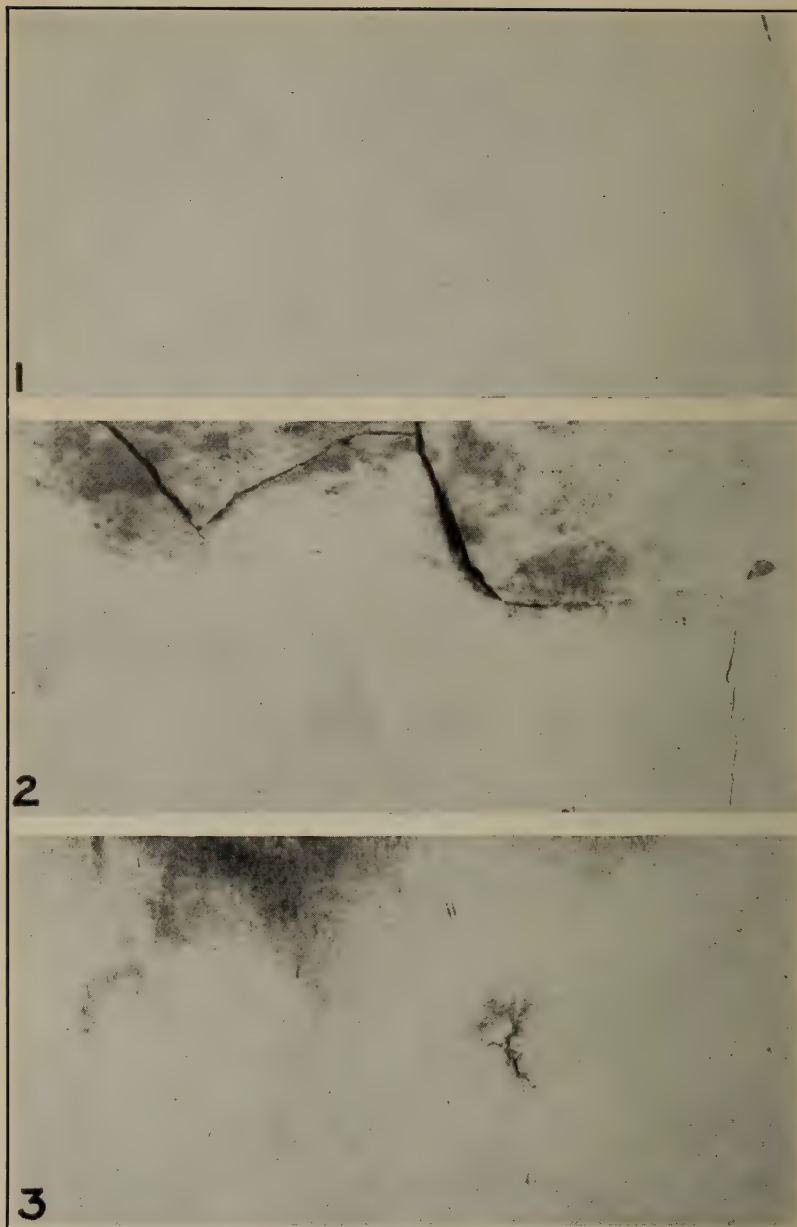


FIG. 1.—Ground-wood pulp sprayed at the Forest Products Laboratory with a 5 per cent solution of borax, inoculated, and stored for a little longer than 14 months. The sample contained approximately 1 pound of dry chemical per 100 pounds wet pulp. It is free from mold and decay

FIG. 2.—Ground-wood pulp sprayed with 0.5 per cent solution of sodium dichromate at the rate of approximately 0.1 pound dry salt per 100 pounds wet pulp. This amount of chemical did not prevent serious decay and molding after 14 months' storage, as shown

FIG. 3.—Ground-wood pulp sprayed with a concentrated solution of sulphite liquor at the rate of 14.7 pounds of solution per 100 pounds wet pulp. After 13½ months' storage the pulp was very badly molded and decayed

TABLE 13.—Preservative treatment of pulps

["A" or "B" appearing in the second column refers to test A or test B described in the text. "S" denotes sulphite pulp. All other was ground wood]

Preservative ¹	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Alphanaphtylamine ²	5.7	Yellow	11	Molded and very rotten.
Do ²	9.3	do	11	Severely molded and decayed.
Do ²	10.1 S		11	Considerably molded and decayed.
Do ²	21.9 S	Slightly brown	11	Somewhat molded and decayed.
Aluminum chloride, c. p.	39.9	None	12	Severely molded and decayed.
Aluminum sulphate, c. p.	88.0	do	12	Do.
Aluminum and potassium sulphate, c. p.	96.9	do	12	Do.
Ammonium bifluoride	10.9	Bleaches	11	Do.
Do	28.9	do	11	Do.
Do	22.9 S	do	11	Do.
Do	46.2 S	Slightly brown	11	Somewhat molded and decayed.
Ammonium carbonate, c. p.	81.4	None	12	Severely molded and decayed.
Ammonium chloride	97.6	do	12	Do.
Ammonium fluoride	14.7		11	Do.
Do	35.4		11	Do.
Do	68.5	Brittle	11	Considerably molded.
Do	14.7 S	Soft	11	Severely decayed.
Do	23.8 S	do	11	Severely molded and decayed.
Do	56.1 S	Slightly brown	11	Severely decayed.
Ammonium nitrate	103.4	None	12	Severely molded and decayed.
Ammonium sulphate	57.5	do	11	Do.
Barium chloride; c. p.	53.2	do	13	Do.
Do	86.5	do	13	Do.
Do	94.8	Slightly brown	12	Slightly molded and decayed. Fair condition at 24 months.
Beta naphthol	1.0	None	13	Severely molded and decayed.
Do	5.7 S	Purple-brown	24	Slightly molded; no decay.
Boric acid ²	24.7 B		7	Good condition; slightly molded.
Do ²	82.2	Pink-brown	13	Slightly molded. Failed before 24 months.
Do ²	126.7 S	Slightly brown	24	Slightly molded.
Borobenzoic acid ^{2,3}	34.3	None	11	Severely molded and decayed.
Do ^{2,3}	63.0 S	Slightly brown	11	Slightly molded. Somewhat worse at 22 months.
Monobromo naphthalene ³	5.3	None	12	Severely molded and decayed.
Do ³	9.4	do	12	Do.
Do ⁴	9.6 S	Slightly brown	12	Somewhat molded; no decay. No change at 24 months.
Calcium benzoate	10.9	None	11	Severely molded and decayed.
Do ²	25.2	do	11	Do.
Do ²	55.4	do	11	Do.
Do ²	23.3 S	do	11	Do.
Do ²	49.8 S	do	11	Do.
Do ²	95.3 S	do	11	Do.
Calcium borate	57.9	do	11	Do.
Do	132.8 S	do	11	Do.
Calcium chlorate	61.2	Yellowish	11	Do.
Do	110.2 S	None	11	Somewhat molded and decayed.
Calcium chloride	86.8	do	12	Severely molded and decayed.
Calcium sulphocarbolate	35.4	do	11	Do.
Do	95.6 S	do	11	No mold or decay. Slightly molded and apparently somewhat decayed at 22 months.
Carbolic acid	19.9	do	13	Somewhat molded; no decay. Failed before 24 months.
Carvacrol oil No. 5 ^{5,6}	37.0 A	do	16	No mold or decay.
Carvacrol oil No. 4 ^{7,6}	37.0 A	Slightly pink	16	Very slightly molded.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative ¹	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Carvacrol oil No. 1 ² , ⁶	37.0 A	None	16	Slightly molded and decayed.
Do.	912.0	Brown	24	Slightly molded; no decay.
Do. ⁴	269.0 S	Slightly brown	24	No mold or decay.
Do. ⁴	463.0 S	do	24	Do.
Chromium sulphate	96.3	Bluish	13	Severely molded; slightly decayed.
Do.	95.1 A	Slightly green	6	Severely molded.
Copper acetate	9.7	None	13	Severely molded and decayed.
Do.	18.5 A	Slightly brown	6	Somewhat molded and decayed. Failed before 16 months.
Do.	18.7	do	13	Somewhat molded and decayed.
Do.	27.8 A		6	Somewhat molded at 6 months; considerably at 16 months.
Do.	37.1	Brown	13	Somewhat molded; no decay. No change at 24 months.
Do.	45.4	do	24	Slightly molded; no decay.
Do.	9.7 S	Slightly brown	12	Slightly molded and decayed.
Do.	20.0 S	do	12	Somewhat molded; no decay.
Do.	41.0 S	Brown	12	Somewhat molded and decayed.
Do.	65.9 S	do	12	Do.
Copper bromide	29.7	Slightly brown	12	Severely molded and decayed.
Copper chloride	17.7	do	13	Severely molded.
Do.	57.4	do	13	Severely molded and decayed.
Do.	89.7	do	13	Severely molded; no decay.
Do.	100.3 S	Brown	12	Somewhat molded; no decay. Somewhat decayed at 24 months.
Copper fluoride	7.4	Slightly brown	11	Severely molded and decayed.
Do.	10.1 S	do	11	Slightly molded; no decay. Severely molded at 22 months.
Copper nitrate, c. p.	40.6	do	13	Severely molded and decayed.
Do.	60.9	do	13	Do.
Do.	64.1 S	do	12	Do.
Copper sulphate	77.9	Brown	13	Severely molded; slightly decayed.
Do.	119.7 S	do	12	Somewhat molded and decayed. Failed before 24 months.
Cymene (crude)	2.0	None	10	Severely molded.
Do.	160.0	do	6	Somewhat molded.
Cymene and naphthalene ⁹ (equal parts by weight).	1.0	do	10	Do.
Do. ⁹	2.0	do	10	Slightly molded.
Do. ⁹	4.0	do	10	No mold or decay.
Dichlorobenzene	2.0	do	6	Slightly molded.
Do.	4.0	do	6	Very slightly molded on outside.
Do.	32.0	do	6	No mold or decay.
Do.	48.0	do	6	Do.
Do.	80.0	do	6	Slight mold on outside.
Ferric chloride, U. S. P.	37.9	Brown	13	Severely molded and decayed.
Ferric nitrate	92.7	Darkened	12	Do.
Ferric sulphate, c. p.	116.3	do	12	Do.
Paraformaldehyde ³	32.1	None	11	Do.
Do. ³	72.9	do	11	Somewhat molded and decayed.
Do. ³	50.9 S	do	11	Slightly molded; no appreciable decay. Considerably molded and decayed at 22 months.
Do. ³	113.0 S	do	11	Severely molded and decayed.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative ¹	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Hydrosilicofluoric acid ¹⁰	44.9	Brown.....	13	Somewhat molded; slightly decayed.
Do.....	95.3	.....	13	Severely molded and decayed.
Lactic acid, U. S. P.....	61.1	Slightly brown.....	12	Do.
Lead acetate.....	45.0	None.....	13	Slightly molded and decayed. No change at 24 months.
Do.....	46.1 A	do.....	6	Severely molded; slightly decayed.
Do. ¹¹	69.4 A	do.....	16	Severely molded; very slightly decayed.
Do.....	76.5	do.....	13	Severely molded and decayed.
Do.....	45.3 S	do.....	12	Do.
Do. ¹²	123.5 S	.....	12	Do.
Lead nitrate.....	90.3	Slightly brown.....	12	Do.
Do.....	99.0 S	Pinkish.....	12	Somewhat molded. Slightly decayed at 24 months.
Lysol.....	96.4	None.....	13	Considerably molded; no decay. No change at 24 months.
Magnesium ammonium chloride.....	102.3	Slightly brown.....	12	Severely molded and decayed.
Magnesium chloride.....	24.9	None.....	13	Do.
Do.....	95.1 A	do.....	16	Do.
Magnesium nitrate, c. p.....	87.6	do.....	12	Do.
Magnesium silicofluoride ¹²	34.1	do.....	11	Severely molded; no appreciable decay. No change at 22 months.
Do.....	52.7	.....	11	Somewhat molded.
Do.....	57.9 S	None.....	11	Considerably molded and decayed.
Do.....	111.1 S	do.....	11	Do.
Magnesium sulphate.....	87.2	do.....	12	Severely molded and decayed.
Manganese sulphate.....	90.2	do.....	12	Do.
Mercuric acetate ¹³	8.1	Slightly brown.....	11	Somewhat molded and decayed.
Do.....	10.6	do.....	11	Do.
Do.....	11.0 S	.....	11	Do.
Do.....	21.8 S	.....	11	Do.
Nickel sulphate.....	36.2	.....	12	Severely molded and decayed.
Mononitrobenzene ¹⁴	6.4	None.....	12	Do.
Do. ³	7.0	do.....	12	Do.
Do. ¹⁵	9.2 A	do.....	6	Severely molded; somewhat decayed.
Do. ¹⁵	13.1 A	do.....	6	Somewhat molded and decayed.
Do. ¹⁴	7.5 S	do.....	12	Somewhat molded; no decay. No change at 24 months.
Dinitrochlorobenzene.....	3.5	do.....	11	Somewhat molded and decayed.
Do.....	6.2	Slightly brown.....	11	Slightly molded. Considerably decayed at 22 months.
Do.....	10.0	Brown.....	11	No mold or decay. Somewhat molded and decayed at 22 months.
Do.....	5.8 S	Slightly brown.....	11	Do.
Do.....	9.9 S	do.....	11	No mold or decay. Slightly molded at 22 months.
Do.....	20.3 S	do.....	11	No mold or decay. Somewhat molded and decayed at 22 months.
Orthonitrophenol ¹⁴	2.1	Slightly yellow.....	12	Severely molded and decayed.
Do. ³	2.4	.....	12	Do.
Do. ¹⁴	4.2	.....	12	Do.
Do. ³	4.3	Yellow.....	12	Do.
Do. ¹⁴	7.0	Slightly brown.....	12	Do.
Do. ³	8.7	.....	12	Do.
Do. ¹⁴	6.8 S	Darkened.....	12	Somewhat molded and decayed.
Do. ¹⁴	9.4 S	.....	12	Considerably molded and decayed.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative ¹	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Paranitrophenol ⁹	2.0	None	6	Severely molded and decayed.
Do. ⁹	4.0	do	6	Somewhat molded and decayed.
Dinitrophenol ⁹	2.0	Slightly yellow	6	Considerably molded.
Do. ⁹	4.0	Somewhat yellow	6	Slightly molded.
Mononitrotoluene	1.0	Slightly brown	6	Severely molded.
Do.	2.0	do	6	Do.
Do.	4.0	do	6	Somewhat molded.
Do. ³	7.2	None	12	Severely molded and decayed.
Do.	8.0	Slightly brown	6	Somewhat molded.
Do. ¹⁴	10.4	None	12	Severely molded and decayed.
Do. ¹⁴	8.4 S	do	12	Somewhat molded; no decay. No change at 24 months.
Orthonitrotoluene ¹⁵	4.6 A		6	Somewhat molded and decayed.
Do. ¹⁵	7.0 A	do	6	Do.
Do. ¹⁵	13.8 A	do	16	No appreciable mold or decay.
Dinitrotoluene ¹⁴	7.1	Slightly yellow	12	Somewhat molded; severely decayed.
Do. ³	8.6	do	12	Severely molded and decayed.
Do. ¹⁴	8.2 S		12	Somewhat molded and decayed.
Oxalic acid	41.9	None	13	Severely molded and decayed.
Do.	79.0	Pinkish	13	Do.
Do.	50.1 S	None	12	Somewhat molded and decayed.
Do.	83.8 S	Purplish	12	Somewhat molded; slightly decayed. No change at 24 months.
Potassium bromate	91.5	None	13	Somewhat molded; no decay. No change at 24 months.
Potassium chlorate	52.6	Brown stains	12	Severely molded and decayed.
Do.	113.0	do	12	Do.
Do.	44.9 S	None	12	Somewhat molded. Also somewhat decayed at 24 months.
Do.	94.4 S	do	12	Severely molded; somewhat decayed.
Potassium permanganate	7.0	Dark brown	13	Severely molded and decayed.
Do.	10.0	do	13	Do.
Do.	15.2	do	13	Do.
Do.	11.4 S	Brown	12	Somewhat molded and decayed.
Do.	14.7 S	do	12	Somewhat molded, severely decayed.
Potassium silicofluoride	11.2	None	11	Severely molded and decayed.
Do.	20.2 S	do	11	Do.
Quebracho extract	104.5	Brown	13	Somewhat decayed. Failed before 24 months.
Do.	202.4	do	13	Somewhat molded. Failed before 24 months.
Salol ¹⁶	6.9	None	11	Severely molded and decayed.
Do. ²	17.9	do	11	Do.
Do. ¹⁶	13.4 S	do	11	Do.
Do. ^{2, 16}	13.8 S	do	11	Do.
Do. ²	26.9 S	do	11	Do.
Sodium acetate	89.8	do	12	Do.
Do.	102.6 S	Brown stains	12	Severely molded; no decay. No change at 24 months.
Sodium aluminate	82.1	Slightly brown	11	Severely molded and decayed.
Do.	118.1 S	do	11	Somewhat molded and decayed.
Sodium arsenate, c. p	43.0	None	24	Slightly molded; no decay.
Do.	97.8	do	24	Do.
Do.	56.7 S	Slightly brown	24	Do.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps—Continued*

Preservative ¹	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Sodium arsenate, c. p.	107.9 S	Slightly brown.....	12	Very slightly molded; no decay. No change at 24 months.
Sodium arsenite, c. p.	102.8	None.....	24	Slightly molded; no decay.
Do.....	94.6 S	do.....	12	Considerably molded; no decay. No change at 24 months.
Sodium benzoate.....	15.3	do.....	11	Severely molded and decayed.
Do.....	41.4	do.....	11	Do.
Do.....	70.5	do.....	11	Do.
Do.....	19.2 S	do.....	11	Do.
Do.....	52.4 S	Slightly brown.....	11	Do.
Do.....	100.2 S	do.....	11	Severely molded; somewhat decayed.
Sodium bicarbonate.....	109.3	Brown.....	12	Severely molded and decayed.
Do.....	203.1	do.....	24	Slightly molded; no decay.
Do.....	106.2 S	Slightly brown.....	24	Do.
Do.....	188.1 S	Brown.....	24	No mold or decay.
Sodium borate (borax).....	54.1 B	.....	7	Severely molded; no decay.
Do.....	83.7 A	Slightly brown.....	6	Considerably molded; no decay. No change at 16 months.
Do.....	90.0	do.....	24	Slightly molded; no decay.
Do. ²	130.2 A	do.....	16	Do.
Do. ²	135.9	do.....	13	Slightly molded and decayed. No change at 24 months.
Do. ²	99.0 S	do.....	12	Slightly molded and decayed.
Sodium bromate, c. p.	81.6	.....	12	Severely molded and decayed.
Do.....	125.7 S	Slightly brown.....	11	Do.
Sodium carbonate.....	124.8	Brown.....	13	Slightly molded; no decay.
Do.....	173.3	do.....	13	Somewhat molded; no decay. No change at 24 months.
Do.....	125.5 S	Slightly brown.....	24	Slightly molded; no decay.
Do.....	204.1 S	Brown.....	12	Somewhat molded; slightly decayed. No change at 24 months.
Sodium chloride (salt).....	174.6	None.....	12	Severely molded and decayed.
Sodium citrate.....	83.5	Slightly brown.....	13	Considerably molded and decayed.
Sodium cyanide.....	91.3	Brown.....	12	Severely molded and decayed.
Do.....	106.5	do.....	12	Do.
Sodium dichromate.....	4.0	None.....	6	Very slight molding.
Do.....	7.9 B	.....	7	No mold or decay.
Do.....	8.0	Slightly darkened.....	6	Very slight molding.
Do.....	10.6	None.....	13	Severely molded and decayed.
Do.....	13.8 A	Slightly yellow.....	16	Very slightly molded; no decay.
Do.....	16.0	Slightly darkened.....	6	No mold or decay.
Do.....	20.6	None.....	13	Severely molded and decayed.
Do.....	27.8 A	Slightly yellow.....	16	Slightly molded; no decay.
Do.....	32.0	Slightly darkened.....	6	No mold or decay.
Do.....	33.5	Slightly yellow.....	13	Somewhat molded and decayed.
Do.....	20.9 S	None.....	24	Slightly molded; no decay.
Do.....	41.3 S	Yellow stains.....	12	Somewhat molded; slightly decayed.
Sodium fluoride.....	8.0	None.....	6	Slightly molded.
Do.....	16.0	do.....	6	Do.
Do.....	18.5 A	do.....	6	Considerably molded; no decay. No change at 16 months.
Do.....	21.9 B	do.....	7	Slightly molded; no decay.
Do.....	27.8 A	do.....	6	Considerably molded; no decay. No change at 16 months.
Do.....	32.0	do.....	6	Very slightly molded.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative ¹	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Sodium fluoride.....	37.2 A	None.....	6	Slightly molded; no decay. No change at 16 months.
Do.....	48.0	do.....	6	No mold or decay.
Do.....	54.7	do.....	12	Slightly molded; no decay. Slightly decayed at 24 months.
Do.....	86.7	do.....	12	Severely molded and decayed.
Do.....	57.1 S	do.....	24	No mold or decay.
Do.....	86.0 S	do.....	24	Slightly molded; no decay.
Sodium nitrate.....	77.4	do.....	12	Severely molded and decayed.
Sodium paranitrophenolate.....	1.1	do.....	13	Do.
Do.....	2.0	Deep yellow.....	13	Do.
Do.....	3.2	do.....	13	Do.
Do.....	10.2	do.....	13	Do.
Do.....	13.8	do.....	13	Do.
Do.....	1.5 S	Slightly yellow.....	12	Do.
Do.....	2.6 S	do.....	12	Do.
Do.....	5.7 S	do.....	12	Somewhat molded and decayed.
Do.....	9.8 S	do.....	12	Severely molded and decayed.
Do.....	22.7 S	do.....	12	Somewhat molded and decayed.
Sodium dinitrophenolate.....	1.1 B	Slightly yellow.....	7	Very slightly molded.
Do.....	1.2 A	do.....	16	Somewhat molded; no decay.
Do.....	1.3	do.....	13	Slightly molded; no decay. Slightly decayed at 24 months.
Do.....	1.5 A	do.....	16	Somewhat molded; no decay.
Do.....	1.9 A	do.....	16	Somewhat molded and decayed.
Do.....	2.1 B	Yellow.....	7	Somewhat molded; no decay.
Do.....	2.1	do.....	13	Somewhat molded; no decay. No change at 24 months.
Do.....	4.6	do.....	13	Somewhat molded and decayed.
Do.....	6.5	Deep yellow.....	13	Slightly molded and decayed. No change at 24 months.
Do.....	10.8	do.....	24	Slightly molded; no decay.
Do.....	1.3 S	do.....	12	Somewhat molded; considerably decayed.
Do.....	2.9 S	Slightly yellow.....	12	No appreciable mold or decay. Slightly molded and decayed at 24 months.
Do.....	6.7 S	Yellow.....	24	No appreciable mold or decay.
Do.....	9.8 S	do.....	12	Somewhat molded; no decay. No change at 24 months.
Do.....	21.3 S	Deep yellow.....	12	No mold or decay. Very slightly molded at 24 months.
Sodium phosphate, monobasic.....	32.8	None.....	12	Severely molded and decayed.
Do.....	80.0	do.....	6	No mold or decay.
Sodium phosphate, dibasic, c. p.....	48.0	do.....	6	Somewhat molded.
Do.....	80.0	do.....	6	Do.
Do.....	95.1 A	do.....	6	No mold or decay. Considerably molded at 16 months.
Sodium phosphate, tribasic.....	48.0	None.....	6	Slightly molded and decayed.
Do.....	80.0	do.....	6	Slightly molded.
Sodium salicylate.....	53.7	Very dark.....	12	Severely molded and decayed.
Do.....	79.8	do.....	12	Do.
Do.....	49.2 S	Slightly brown.....	12	Severely molded; no decay.
Do.....	96.4 S	do.....	12	Do.
Sodium silicofluoride.....	34.1	None.....	11	Slightly molded and decayed. No change at 24 months.
Do.....	59.2 S	do.....	11	Do.
Sodium sulphite, c. p.....	157.7	Slightly brown.....	12	Severely molded; considerably decayed.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative ¹	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Sodium sulphocarbolate.....	56.4	None.....	11	Severely molded and decayed.
Do.....	114.1 S	do.....	11	Considerably molded and decayed.
Sodium and potassium tartrate, c. p.	75.4	Slightly brown.....	12	Severely molded and decayed.
Sodium thiosulphate (hypo).....	218.5	None.....	12	Do.
Sumach extract.....	192.4	Brown.....	12	Do.
Thymol.....	0.2	None.....	13	Do.
Do.....	0.4	do.....	13	Considerably molded and decayed.
Do.....	0.9 A	do.....	6	Slightly molded and decayed. No change at 16 months.
Do.....	0.9	do.....	13	Considerably molded and decayed.
Do.....	1.9 A	do.....	6	Slightly molded and decayed. Somewhat worse at 16 months.
Thymol oil No. 2 ⁶ , ¹⁷	18.5 A	do.....	16	Slightly molded; no decay.
Do. ⁶ , ¹⁷	37.0 A	do.....	16	No mold or decay.
Thymol oil No. 3 ⁶ , ¹⁸	37.0 A	do.....	16	Very slightly molded.
Thymol.....	0.9 S	do.....	12	Severely molded; somewhat decayed.
Zinc chloride.....	108.6	Darkened.....	12	Severely molded; no decay. No change at 24 months.
Do.....	105.8 S	do.....	12	Severely molded; somewhat decayed.
Zinc silicofluoride.....	32.9	None.....	11	Somewhat molded; no decay. No change at 22 months.
Do.....	57.7	do.....	11	Somewhat molded; no decay. Somewhat decayed at 22 months.
Do.....	80.0	do.....	6	Slightly molded.
Do.....	53.5 S	do.....	11	Slightly molded; no decay. Slightly decayed at 22 months.
Do.....	104.5 S	do.....	11	Slightly molded; considerably decayed. No change at 22 months.
Zinc sulphate, c. p.....	95.7	Slightly brown.....	13	Severely molded; no decay.
Zinc sulphocarbolate.....	57.4	None.....	11	Severely molded; considerably decayed.
Do.....	106.2 S	do.....	11	No appreciable mold or decay. Slightly molded and decayed at 22 months.

¹ Unless otherwise indicated, the chemicals were of "technical" quality.

² Solutions applied warm or hot.

³ Saturated solution with some chemical in suspension.

⁴ Diluted with 95 per cent alcohol.

⁵ Volatile oil of *Monarda fistulosa*, yielding carvacrol. Prepared and donated by the department of chemistry, University of Wisconsin (oil No. 5).

⁶ The emulsions of oils No. 1, 2, 3, 4, and 5 were made in the following manner, using rosin size of about the same concentration as in 15. The rosin size was not cleared by use of excess sodium hydroxide. The oils added in small amounts were shaken with an equal volume of the emulsifying agent, then diluted to 15,000 c. c. with water. The amounts of oil and emulsifying agent used were: No. 1 with equal volume of rosin size, slightly alkaline. No. 2 with equal volume of rosin size, plus 0.1 volume of saponin solution. No. 3 with equal volume of rosin size, plus 0.4 volume of saponin solution. No. 4 with equal volume of rosin size. No. 5 with equal volume of rosin size, plus 0.1 volume of saponin solution.

⁷ Phenol portion of 5 (oil No. 4).

⁸ Nonphenol portion of 5 (oil No. 1).

⁹ The undissolved portion of solid chemical was put on surface of pulp.

¹⁰ This chemical appears to attack the fiber and weaken the pulp. It gives a pinkish cast to the pulp.

¹¹ Solution made up in zinc-lined vessel, and lead precipitated out.

¹² Appears to weaken the pulp.

¹³ On exposure to air and light solution forms red mercuric oxide.

¹⁴ Strong solution made up in 95 per cent alcohol and diluted to the desired concentration with water.

¹⁵ The emulsions of nitrobenzene and orthonitrotoluene were made by shaking with the oils an equal volume of rosin size, of about the same concentration used in the paper mill, which had been previously cleared by adding NaOH solution. The oils were added in small amounts to the size solution and well shaken before adding the next portion. This gives an emulsion with the oils as the discontinuous phase and water as the continuous phase.

¹⁶ First sprayed with salol, then with 0.5 per cent sodium carbonate.

¹⁷ Volatile oil of *Monarda punctata*, yielding thymol. Prepared and donated by the department of chemistry, University of Wisconsin (oil No. 2).

¹⁸ Nonphenol portion of 17 (oil No. 3).

REQUIREMENTS A PRESERVATIVE MUST MEET TO BE SUITABLE

In the selection of a preservative, several characteristics besides effectiveness as an antiseptic must be given consideration, such as:

1. Poisonous properties.
2. Chemical discoloration produced in the pulp.
3. Odor.
4. Solubility in cold water.
5. In the case of oils, ease of emulsification.
6. Cheapness and availability.

Some substances which are quite efficient as antiseptics must necessarily be ruled out of commercial use, because in the handling of either the solutions or the sprayed pulp sufficient quantities of the poison might be absorbed through the skin to impair the health of the worker. Likewise, violent poisons which might accidentally enter the body through the mouth must be avoided in order to protect the consumer. Examples of such dangerous substances are mercuric chloride (corrosive sublimate), sodium arsenate, and sodium cyanide.

Some highly efficient antiseptics produce objectionable discolorations in the treated pulp, which are due either to the color of the chemical or to caustic or other action on the wood fiber. All of the alkalis produce browning, the depth of which depends on the substance used and the concentration of the solution employed. For instance, borax produces a slight browning which is not objectionable, whereas both sodium carbonate and sodium bicarbonate will so distinctly darken the pulp as to make it unfit for commercial use unless it is to be bleached later. Sodium dichromate, likewise, ultimately browns the pulp to a considerable degree if applied at a rate of 20 pounds or more per ton. At some mills there might be objection to this darkening, but at the mill where the tests were made there seemed to be no objection to it. Sodium dinitrophenolate is apparently not adapted to commercial use on ground wood in amounts larger than 2 pounds per ton. Even at 0.9 pound per ton the yellow tint produced, though it readily leaves the pulp on washing, is distinctly noticeable.

None of the substances recommended hereafter give rise to objectionable odors, but the opposite is true of some of the chemicals experimented with.

Solubility in cold water is a very important property, as in most cases the chemicals are most easily applied in the form of water solutions.

Oils are preferably to be emulsified in order to secure the proper dilution. The readiness with which they emulsify is an important factor in their application.

Of course, price and availability will have much to do with the selection of the chemical to use. The results from the treatment must justify the cost of it. How much the treatment will cost depends largely on how much of the chemical is necessary to treat a unit of pulp effectively.

CHEMICALS GIVING MOST FAVORABLE RESULTS

Of the chemicals tried, six gave favorable results in preventing mold and decay and also met other requirements sufficiently well to warrant their commercial consideration. Brief information concerning these follows.

Borax is a white substance, 5.3 per cent soluble in water at 70° F. and 7.4 per cent at 86° F. It is nonpoisonous and therefore safe for workmen to handle. It slightly darkens the pulp but not to an objectionable degree. About 17 pounds of ground wood and 5 pounds of sulphite were treated with borax at the laboratory; 450 pounds of ground wood were treated at the mills. The borax treatments at the laboratory held the pulp in good condition (with slight molding in a few cases) for six to eight months. Tests lasting for from 13 to 24 months gave quite satisfactory results. (See Pl. XIV, fig. 1.) The mill tests, with 54 to 84 pounds of chemical per ton dripped on the pulp back of the press rolls, were not so favorable, the pulp having molded considerably within six months.

Boric acid is 4.8 per cent soluble in water at 68° F. and is colorless in solution. It is nonpoisonous and safe to use, but more expensive than borax. It gives a slight pinkish-brown color to ground wood. About 10 pounds of ground wood and 4 pounds of sulphite were treated with boric acid at the laboratory; 160 pounds of ground wood were treated at the mill. After six months, the pulp was somewhat molded but in fairly good condition. After 12 to 13 months it was still in fair condition, with no active decay present.

Cymene-naphthalene mixture.—Spruce turpentine (crude cymene) is a reddish-brown liquid by-product of the sulphite mill. Naphthalene is the white substance used commonly as moth balls. It is 33 $\frac{1}{3}$ per cent soluble in cymene at 122° F.

Pulp treated with naphthalene alone remained in good condition directly under the crystals, but became badly molded elsewhere. (Pl. XV, fig. 1.) With cymene alone, severe molding occurred. (Pl. XV, fig. 2.) About 150 pounds of ground-wood pulp were treated with mixtures of equal parts by weight of the two substances. Four pounds per ton of this mixture preserved the pulp perfectly for 10 months. The writers advise the use of 1 $\frac{1}{2}$ pounds of naphthalene dissolved in 6 pounds of cymene to a ton of dry pulp. To facilitate uniform application, the chemicals should be emulsified with the aid of rosin soap and diluted with water. (Pl. XV, figs. 3 and 4.)

Sodium fluoride is a white salt 4.3 per cent soluble in water at 64° F. It is perfectly safe for workmen to handle and causes no chemical discoloration of the pulp. At the laboratory about 11 pounds each of ground wood and sulphite were treated with sodium fluoride; at the mills 735 pounds of ground wood were so treated. The mill application of 18 to 28 pounds of chemical per ton gave somewhat variable results up to 16 months, the pulp in some cases being only slightly blue-black molded and in others rather badly so. It was, however, free from decay. Thirty-seven pounds per ton preserved the pulp very well, permitting only slight molding after 16 months. Part of the pulp at the mill was somewhat molded after six months, but not seriously.

Sodium dinitrophenolate is a yellow salt producing a yellow solution. It is approximately 2.4 per cent soluble in water at 59° F. Although in its concentrated form it is considered an industrial poison, it is thought that in the dilution hereinafter recommended it will not injure the health of workmen, provided reasonable care be exercised. In the lower concentrations it colors the pulp slightly yellow, and in the higher distinctly so. This color readily washes out, but the

washed pulp may be left somewhat darker than normal. About 14 pounds of ground wood and 22 pounds of sulphite were treated with sodium dinitrophenolate at the laboratory; 430 pounds of ground wood were treated at the mill. From 1 to 2 pounds of chemical per ton preserved the pulp from decay for periods up to 16 months, but did not prevent all molding. Up to six months these concentrations proved highly efficient. On sulphite, 3 pounds per ton almost perfectly preserved the pulp for 24 months. Concentrations of 4 pounds and higher are somewhat more effective, but they color the pulp rather too yellow.

Sodium dichromate is a reddish-brown substance readily soluble in cold water, yielding an orange-yellow solution. When applied at the rate of about 30 pounds per ton it immediately stains the pulp a slight yellow, and the discoloration, on standing, becomes brownish, darkening the pulp somewhat. Although classed as a poison, sodium dichromate is not considered dangerous to handle. About 45 pounds of ground wood and 11 pounds of sulphite were treated with this preservative at the laboratory; 230 pounds of ground wood were treated at the mills. The addition of 8 pounds of chemical per ton at one mill preserved the pulp for seven months. From 14 to 28 pounds of chemical per ton at another mill permitted only slight molding in 16 months. The laboratory results were not so good. Ten pounds per ton preserved the pulp for three months but failed in six months. (Pl. XIV, fig. 2.) From 20 to 33 pounds per ton kept it in rather good condition for 6 months, but failed in 13 months. The sulphite pulp held up better than ground wood.

COMMENTS ON OTHER CHEMICALS

Beta naphthol (1 pound per ton) failed, under a severe laboratory test, to preserve ground wood for as long as 13 months, but 6 pounds per ton almost perfectly preserved sulphite pulp for 2 years. Because this substance is but slightly soluble in water, it was applied in suspension. Dusting the dry chemical on the pulp may prove a better procedure.

Copper acetate gave unfavorable results when used at the rate of 10 pounds per ton. Thirty-seven pounds per ton gave rather good results. It browns the pulp considerably.

Copper acetoarsenite (Paris green) gave efficient protection when used at a rate of 7 pounds per ton. It is too poisonous to handle, however, and gives a deep green surface discoloration to the pulp.

Copper sulphate at a rate of 78 pounds per ton gave considerable protection.

Dichlorobenzol was highly effective in the excessive amounts employed, and further tests should be made at lower concentrations. It was used in the form of a crude oil, but dilute emulsions in water probably can be easily made. It is volatile, and the odors are oppressive in a closed space but not particularly poisonous. It is used in the crystalline form as a very effective insecticide in herbaria, etc.

Dinitrochlorobenzol proved very effective when applied at the rate of 6 pounds per ton, but on account of its highly poisonous properties it can not be recommended as a pulp preservative.

Lysol (96 pounds per ton) protected the pulp from decay but permitted severe molding.

Magnesium silicofluoride (53 pounds per ton) and *zinc silicofluoride* (33 pounds per ton) gave a considerable measure of protection, but further data are needed in regard to their possible action in weakening the pulp.

Sodium arsenate (43 pounds per ton) and *sodium arsenite* (102 pounds per ton) protected the pulp to a considerable extent, but on account of their highly poisonous character can not be recommended.

Sodium bicarbonate, ordinary baking soda, browned the pulp as did sodium carbonate, and also apparently softened it.

Sodium carbonate, a white salt readily soluble in cold water, is a fairly strong alkali. It was found to brown the pulp to a marked degree. The discoloration readily bleaches out of sulphite pulp, without increased bleach consumption, but the pulp is somewhat softened by the action of the alkali.

Thymol gave considerable protection in some cases, but the results were too erratic to warrant recommendation until further and more uniformly favorable data are obtained. The mill tests (none were made at the laboratory) of the two distillates from the thymol-yielding plant *Monarda punctata* resulted very favorably. However, large quantities of these distillates are not available at present.

Mill tests of the three distillates from the carvacrol-yielding plant *Monarda fistulosa* also gave favorable results. Production of these distillates on a commercial scale would perhaps bring their cost low enough to permit their use.

Zinc chloride (108 pounds per ton) gave very favorable results in preserving the pulp against decay but permitted heavy infections of speckled gray mold.

The following preservatives, in addition to those listed in Table 13, have for various reasons proved unsatisfactory under the severe conditions imposed in the laboratory tests: Calcium hydrate, copper oleate, formaldehyde, formic acid, mercuric chloride, naphthalene (dry and in alcoholic solution), rongalite, sodium bifluoride, bleach liquor, and fresh and waste sulphite liquor. (Pl. XIV, fig. 3.)

PREVALENCE OF VARIOUS FUNGI ON TREATED PULP

The molds most commonly found on the experimental pulp, listed in the order of their frequency of occurrence, were those respectively producing neutral gray, pink, purple, and yellow spots or blotches. Neutral gray discolorations were attributable to any one of several molds that have brown mycelia. Species of *Penicillium* and *Fusarium* produced discolorations pink to purple in tint, and some species of *Trichoderma* caused yellow areas.

Gray discolorations were found quite generally throughout the packs. Certain molds were more frequently found on the outer laps and along the edges and folds than elsewhere. The ammonium salts, sodium chloride, and sulphite liquors seemed to stimulate all kinds of fungous growth. Pulp which had been sprayed with copper nitrate, lead acetate,⁴ and zinc chloride was found covered with numerous minute gray specks.

Mercuric chloride permitted the light-colored molds, *Penicillium* and *Trichoderma* especially to develop.

⁴ When prepared in zinc-lined vessels, this salt was largely changed over to zinc acetate.

Alphanaphtylamine, aluminum fluoride, aluminum sulphate, potassium bromate, potassium permanganate, salol, sodium aluminate, and sodium sulphocarbolate seemed to check all the molds except those causing the neutral gray discolorations, but they did not control the wood-destroying fungi.

Potassium permanganate colored the pulp a dark brown, but the wood-destroying fungi bleached out this color.

PRESERVATIVES RECOMMENDED FOR MILL APPLICATION

Of the preservatives reported upon, sodium fluoride shows the highest antiseptic effectiveness and the fewest objectionable features for mill application. Cost is the main objection to it. Borax is a close second.

Boric (boracic) acid is equal or somewhat superior to borax, but its greater cost throws it out of competition.

A combination of naphthalene and cymene in the proportions recommended above, promises to be nearly as effective as sodium fluoride, and is very much cheaper.

Sodium dinitrophenolate, applied at the rate of 2 pounds per ton, appears very promising. In antiseptic efficiency it is equal to anything tried, but the yellowish chemical discoloration it causes may render the pulp objectionable for some purposes. This stain, however, readily washes out, although it may leave the pulp somewhat browner than normal.

Sodium dichromate did not seem to give quite as good results as the four substances just mentioned. Its antiseptic efficiency varied rather too widely in the tests, and its tendency toward browning of the pulp was rather marked, particularly when applied at a rate of 32 pounds per ton.

Preservative solutions should be applied at the press roll, in which case the retention is about 70 per cent for a 5 per cent solution. The loss of chemical in the white water must be compensated for in order to get the necessary actual concentration in the pulp. There is no danger of the treated pulp sticking to the rolls.

Preservative solutions can not be effectively applied to pulp in storage, either before or after infection has taken place. Any method of dipping or spraying that would be satisfactory would not be economically feasible. It thus appears a much simpler matter to prevent the development of molds and decay than to stop it.

Aside from technical difficulties in application the deciding factor in the commercial use of any chemical is its cost, and this fact has not been lost sight of in this investigation.

On the assumption that the pulp normally leaves the wet machine one-third dry, the cost of various chemicals per ton of air-dry pulp, at the market prices of July 9, 1923, would be as follows:

	Cost per ton of pulp
Borax, 80 pounds per ton, at $5\frac{1}{4}$ cents per pound.....	\$4. 20
Boric acid, 80 pounds per ton, at 10 cents per pound.....	8. 00
Crude cymene, 6 pounds per ton, at $6\frac{1}{4}$ cents per pound, and crude naphthalene, $1\frac{1}{2}$ pounds per ton, at 3 cents per pound.....	. 42
Sodium fluoride, 48 pounds per ton, at $8\frac{3}{4}$ cents per pound.....	4. 20
Sodium dinitrophenolate, 2 pounds per ton, at 40 cents per pound (for dinitrophenol).....	. 80
Sodium dichromate, 16 pounds per ton, at 8 cents per pound.....	1. 28

In some cases the amount of chemical recommended above is less than that indicated in Table 13 as the effective quantity, but it should be borne in mind that there was a much greater loss of chemical from diffusion in the laboratory tests than would obtain in industrial practice.

In order to gain some idea of what additional expense the mills would consider practical for safeguarding pulp to be stored for any considerable time, a number of questionnaires were sent out in May, 1921. Twenty-three replies were received. The estimates of the nine companies submitting definite figures varied from \$1.25 to \$6 per ton, the average for maximum figures being about \$3.50. On this basis only three of the preservatives suggested herein would be available, namely, cymene-naphthalene mixture, sodium dinitrophenolate, and sodium dichromate; but improved methods of applying the preservatives, so that a greater amount will be retained by the pulp, may hereafter permit the use of lower concentrations and thus make possible the use of some of the more expensive chemicals.

SUMMARY

An extensive survey of storage conditions at pulp and paper mills indicates that serious losses occur both in stored wood and in pulp, especially ground wood. Storage conditions in the woods and at the mill can be improved so as to reduce these losses.

The deterioration of wood and wood pulp is due mainly to fungi. For practical purposes these fungi may be divided into two general groups—molds and wood-destroying organisms. The former discolour the pulp but do not appreciably affect its strength; the latter produce true decay.

The character of the wood available for pulping is an important factor in its storage. Pulp wood usually consists of the less durable species. The length of storage, the time of cutting, the removal of bark, the presence of insects, methods of piling, and general sanitation about the yards are all conditions which affect the life of wood. The prevailing methods of storing wood are discussed in detail, and the desirability of segregating infected from sound wood and of pulping all wood in rotation is emphasized.

In order to demonstrate the difficulties met with and the large losses sustained in the use of decayed wood, a considerable amount of wood in various stages of decay was pulped by the mechanical, sulphite, and soda processes. The grinder runs on (spruce) wood which had been stored for three years under unfavorable conditions demonstrated a loss in yield of 16 per cent, based on weight of oven-dry barked wood. The resulting pulp was freer, contained a larger number of shives, and was decidedly darker in color than pulp made from sound wood. In the manufacture of chemical pulps, chipping losses ranged as high as 17 per cent for badly decayed material as compared with 4.4 per cent for sound material. The

NOTE.—Final conclusions as to the value of decayed wood, in general, for chemical pulp should not be drawn from the specific data presented in this bulletin. The value of decayed wood for sulphite pulp is closely associated with the chemical action of the wood-destroying organisms, and these organisms vary widely in their method of attack. Further investigations, under way at the Forest Products Laboratory, indicate already that some types of rot tend to reduce the value of wood for sulphite pulp less than the superficial appearance of the wood might suggest.

yields of screened sulphite pulp were not, as a rule, much lower than the yield from sound spruce. These yields, however, being figured on an oven-dry weight basis for both the wood and the pulp, do not represent the actual loss. If the yields per cord could have been determined, a distinct lowering with increased decay would have been demonstrated. Soda cooks required more chemical for decayed wood than for sound, since the portion that had decayed was more readily soluble in the cooking liquor. When the pulp was undercooked, screenings were about 17 per cent, with a yield of only 32 per cent. In these experiments the chemical pulps from decayed woods were lower in strength, showed less endurance against folding, and were exceptionally dirty.

Chemical analyses of various sound and decayed woods explain the losses that occur through decay. The principal changes are marked increases in constituents soluble in hot and cold water and in alkali, indicating changes in the character of the cellulose from a resistant to a less stable form. The lignin does not appear to be destroyed in any appreciable amount. In the case of pulp (spruce, sulphite) made from decayed wood, decay is likewise reflected in increased solubility in water and NaOH and lessened stability of the cellulose. It is thus evident that a qualitative parallelism exists between decayed wood and the mechanical and sulphite pulps made from it.

In present commercial practice pulp is usually stored in large piles in the open or placed in closed unheated sheds or in the basements of mills. As a result of manufacturing conditions, ground wood is frequently stored for 6 to 12 months, or even longer. Chemical pulps are, for the greater part, converted immediately, or within a few months. Deterioration during storage is often severe, particularly with ground wood, and is due both to molds and to wood-destroying fungi. Molds, though not affecting the strength of the pulp, discolor it and frequently bind together the pulp particles so that the molded spots or areas do not beat up well, and a lumpy, speckled paper results. Wood destroyers decrease the strength of the wood fibers and render them so brittle that they break into short lengths in the beater, with the result that much of the pulp is lost in the white water and the manufactured paper has little strength. The combined action of molds and wood-destroying fungi thus results in the production of paper of very poor color and quality.

In order to combat deterioration of pulp during storage, careful attention must be given to the elimination of sources of infection. Pulp may become infected with molds either through the spores which abound in the air and in the water used in manufacturing processes, or by direct contact of moldy with clean pulp. Infection by wood destroyers more often occurs through contact with infected pulp or wood, but it may also occur through secondary spores produced on the fungus mycelium, or through spores of the more common type, produced on the fruit bodies which develop on wood in the form of conchs, brackets, toadstools, mushrooms, leathery incrustations, etc. Humus soil also appears to be an important source of infection for both molds and wood-destroying fungi. This may be carried about on the workmen's clothing or shoes.

The physical characteristics of pulp which has decayed in storage are similar to those of pulp made from badly decayed wood. Such

pulp is much freer than sound pulp, is brash and brittle, foams badly, and tends to stick to the couch and press rolls. The paper made from it is considerably darker and much weaker than that from sound, and only one-tenth as resistant to ink penetration. Ground wood made from decayed wood deteriorates more rapidly during storage than that made from sound wood, in spite of the apparent destruction of most of the fungi in the original wood during the grinding process.

The most feasible method of controlling deterioration in pulp during storage, in addition to the adoption of the precautions against infection already indicated, is to introduce an antiseptic into the pulp on the wet machine. One hundred and twelve chemicals were tested for this purpose. About 3,000 small ground-wood laps and 1,400 sulphite laps were treated at the laboratory, and about 7,200 pounds of ground-wood pulp at the mill. The chemicals that best filled the requirements for a preservative were borax, boric acid, a solution of naphthalene in crude cymene, sodium fluoride, sodium dinitrophenolate, and sodium dichromate.

In the appendix will be found a record of studies, more comprehensive than any hitherto undertaken, of the fungi which inhabit pulp. Through these studies it was determined for the first time that the principal chemical damage to pulp is attributable to the hymenomycete fungi rather than to any of the molds. Sixteen hymenomycetes were isolated, but only one was completely identified, owing to the great difficulty of developing characteristic fruit bodies in culture. The various fungi are described, and in addition to the morphological grouping there is presented a new scheme of classification of these fungi which is based on the color reactions of pulp infected by them.

In the appendix is also reported the first extensive investigation of the chemical action of fungi on ground-wood pulp.

APPENDIX

STUDIES OF SPECIFIC FUNGI THAT DETERIORATE WOOD PULP

Up to the present no careful systematic study of pulp-inhabiting fungi has been made. As far as is known by the writers, investigators in the past have ignored the hymenomycetes entirely, owing to the fact that before this study was undertaken no one used cultural methods in studying pulp fungi. The hymenomycetes can not often be detected by a mere examination of the pulp. Areas infected with them are commonly overrun by molds, which accounts for the fact that certain authors attribute serious decay of pulp to some of the molds.

In the course of the investigation a large number of fungi have been isolated from pulp and wood. In this appendix are presented the cultural characters of the fungi isolated, together with a classification of these fungi based on the color changes which they produce in the pulp.

Many of the organisms were grown on ground-wood pulp in order to determine their specific effect on the fiber. In general, it was found that the loss in weight produced by molds was slight, the greatest loss being 3.2 per cent in 12 months. Wood-destroying fungi (hymenomycetes), on the other hand, produced losses as high as 49.5 per cent within the same period. Analyses of the various samples showed that the effect of molds on the chemical constitution of the fiber was likewise slight, but that wood-destroying fungi produced very marked changes in this respect also.

WORK OF PRIOR INVESTIGATORS

Cellulose fermentation is the outstanding factor in the decay of both wood and pulp. It is known to be caused by certain hymenomycetes (among which are wood-destroying fungi), to a lesser extent by some of the fungi commonly called molds, and, more rarely, by certain groups of bacteria. The relative destructiveness of the first two groups, so far as concerns pulp in particular, has only lately been recognized—although for 70 years or more the general subject of cellulose fermentation has repeatedly attracted the attention of investigators. In 1850 Mitscherlich (17) first attributed the fermentation of cellulose to microorganisms. Workers immediately following Mitscherlich interested themselves not in the organisms causing cellulose fermentation, but rather in the products these organisms formed in the fermentation processes. After about 25 years investigators became interested in the organisms themselves, but more attention was then given to bacteria than to fungi.

To Van Iterson (13) belongs the credit for the first systematic study, as late as 1904, of cellulose fermentation induced by fungi. His method was the following: Two sterile sheets of pure filter paper were placed in a Petri dish and moistened with tap water in which

ammonium nitrate and monobasic potassium phosphate were dissolved in the ratio 100: 0.05: 0.50; for inoculation, soil or humus was used, or the dishes were exposed to the air. The species were then separated on malt gelatin and tested for their cellulose-fermenting ability. Many active cellulose destroyers were thus obtained. In order to determine the abundance of mold spores in the air, Van Iterson exposed in the garden for 12 hours a Petri dish having a surface of 275 square centimeters and containing moistened filter paper. One hundred and fifty-two mold colonies developed, representing 35 different species. Fifteen cellulose destroyers in all were isolated and described in the course of this first investigation.

McBeth and Scales (16) list 16 different species as being able to destroy cellulose more or less rapidly, and point out that fungi are not so largely confined to acid soils as is generally believed. They hold that cellulose destruction in soil is largely due to the work of filamentous fungi.

Hartig (9) and a large number of other workers have recognized the part that the higher fungi, the hymenomycetes, which we commonly call wood-destroying fungi, play in the destruction of cellulose and other constituents of wood.

Of the fungi which infect wood pulp, however, very few investigations have heretofore been made, although notes concerning the deterioration of paper date back to the early part of the eighteenth century. At that time, and until recently, the spotting of paper was attributed to the work of larvæ.

In 1896 Klemm in Germany (14), published a short paper in which it is stated that the most common, as well as the most detrimental, of pulp-inhabiting fungi is *Rhynchospheeria* sp. This mold is reported as appearing either as brown or dark-green spots with dark centers from which radiate delicate branched threads, or as numerous spots grouped together in blotches or in parallel lines of a gray color. Klemm attributed the uneven distribution to the mode of infection. This fungus, he showed, is propagated by two kinds of spores—ascospores, produced in asci (sacs) in perithecia, minute flask-shaped bodies with long narrow necks; and dark colored cells (chlamydospores) produced in chains in the mycelium. Chlamydospores are by far the more common. The perithecia were seen only occasionally on the surface of old pulp.

Klemm pointed out, also, that some organisms, although very destructive, are difficult to detect because they produce no discoloration. Pulp thus infected produces a paper which may rapidly become weak and brittle. It is quite evident that these fungi are the true wood destroyers, hymenomycetes, but Klemm did not seem to recognize them as such. He noted that *Stachybotrys atra* Cda., a "sooty" mold, is frequently present in large quantities, and that its spores cause a perceptible darkening of the pulp. Mention is made also of a mold, found on old pulp, which forms small, black, globe-like bodies surrounded by a yellow or brown spot. The conclusion is reached, however, that both this mold and *Stachybotrys atra* are relatively harmless, since their mycelia do not pierce, but only interlace, the wood fibers.

Barnes (2), while working as chemist for a large paper mill, observed mechanical wood pulp which was seriously damaged by rot—some of it rendered 20 to 25 per cent soluble in water and utterly ruined.

During three years many shipments of Scandinavian and Canadian pulps received were more or less damaged by "fungoid growth and rot." Microscopic examinations of the pulps were made, in an attempt to determine the cause of the deterioration. Barnes stated that the chief effect was a blackish discoloration produced by a species of *Cladosporium*, which he held responsible in most cases for the systematic decay of ground-wood pulp. There is shown a rough drawing of a "type of white fungus growing on the surface of the sheets in the interior of a bale of mechanical pulp." This was probably a hymenomycete. He considered the "fission fungi" (evidently, to judge from his figure, *Penicillium* sp.) to be the cause of the rapid decay of external parts of laps already infected with *Cladosporium* sp. He noted molds producing brick-red, yellow, and violet pulp, but remarks that they had very little "tendering" effect upon the pulp. In one series of tests various conspicuous spots were marked on the laps with a violet pencil; the marked laps were then piled in a compact stack and surrounded by moist sound ground wood. At the end of the six weeks it was found that all spots, including the "grayish markings due to reaction of iron and tannin bodies," had increased in size, and that the white branching fungus had grown far into the bale.

Sée (24) has made a rather thorough study of the fungi found on paper. He isolated 27 species belonging to 16 genera. As to their source, he states that the spores of the fungi are in the paper when it is made, but apparently he made no tests to substantiate his assertion. The assumption is based upon the presence of the same species on both paper and pulp.

Moreau (18) reports a very much blackened condition of imported pulp, supposedly due to the presence of a sphaeriaceous fungus. He advised that antiseptic measures be taken before shipping, because the presence of large quantities of the fungus would necessitate the use of excessive amounts of hypochlorite for bleaching.

In the review (4) of the work of Beadle and Stevens the most interesting fact, from the present standpoint, to be developed is that blue stain, caused by *Ceratostomella* spp., sometimes gives rise to trouble in paper making. The authors are inclined to believe that these species have a weakening effect upon mechanical pulp. Their spores are produced in long, beaked perithecia at the ends of logs or in cracks and holes.

The only hymenomycetes reported in the literature as inhabiting pulp are *Paxillus panuoides* Fr. and *Trametes serialis* Fr., observed by Von Schrenk at Glens Falls, N. Y. (21), whereas in the present investigation it has been conclusively shown not only that the hymenomycetes are present but also that they are responsible for the greatest amount of damage to pulp. It seems probable that had careful culture experiments been run, the previous investigators would have found hymenomycetes mixed with such molds as *Rhynchosphaeria* and *Cladosporium*, which they reported responsible for pulp decay. Without isolation studies it would have been easy indeed to mistake the more evident molds for the really destructive hymenomycetes.

MATERIALS AND METHODS EMPLOYED

In the study here reported, fungi were isolated from 18 samples of ground wood, 5 samples of sulphite pulp, 1 sample of soda pulp, 8 pulp logs, 7 boards taken from pulp sheds, 1 sample of white water, and 4 samples of river water. Although no attempt was made to obtain in pure culture all of the fungi that are in any way responsible for the deterioration of wood pulp, the writers nevertheless feel confident that they have isolated all of the more serious enemies common to pulp in the localities from which pulp samples were received. These samples, either in single laps or in larger amounts up to approximately half a ton, were submitted from mills in New York, Wisconsin, Minnesota, and Canada. Other samples of water were plated out, but since they yielded neither cellulose-dissolving molds nor hymenomycetes, no further study of them was made, nor were the cultures which they produced retained.

All culture work was performed in a culture case kept sterile by careful washing out with mercuric chloride solution (1:1000) before each using.

For general purposes, plain malt agar, made up according to the following formula, was found to be a very favorable medium:

Distilled water.....	cubic centimeters..	1, 000
Trommer's plain malt extract.....	grams.....	25
Agar-agar, powdered or Bacto (acidity not adjusted).....	do.....	15

Approximately 20 cubic centimeters were put in each test tube. After sterilization the medium was poured from the tubes into sterile Petri dishes, 3 or 4 drops of 5 per cent lactic acid having been added to half the tubes just prior to pouring. Both plain and acidified plates were then used in plating out the pulp samples. In special cases, in which the fungus could not be made to grow upon the plain malt medium, potato, carrot, bean, prune, and oatmeal agars were tried. In no case, however, were cultures obtained on these special media when they would not grow on the plain malt agar. For making cultures from river water, McBeth and Scale's cellulose agar was used.

Characteristic spots on the pulp were selected. In the comparatively few cases in which surface spores were present, a platinum loop full of sterile water was brought into contact and the adherent spores were transferred to a sterile tube containing about 2 cubic centimeters of distilled water. After a thorough shaking of this first tube further dilutions were made. Then a few drops of the spore suspensions were poured upon plain malt and acidified plates, and each plate was shaken gently until the entire surface was covered with a thin layer of the water. The plates were then incubated at 25 to 30° C. for the necessary period, which varies considerably with the various species of fungi. If the colonies on the plates were fairly uniform and sufficiently scattered, some of them were transferred to malt slants before any of them had sporulated. If mixed cultures were obtained, as was usually the case, the best plates were held until the desired fungus sporulated, when more plates would be made from it and the process repeated until pure cultures were obtained.

On the majority of the pulp samples, however, the spots were apparently pigmented or bleached areas with no superficial spores, and the process above described was not applicable. In such in-

stances the more isolated spots were selected. The outer layers of the pulp were carefully folded back with a sterile needle, and some of the infected pulp from the interior of the sheet was transferred to plain malt and acidified plates. Usually three of each kind of plates were inoculated, but when the infection of the pulp was unusually heavy many more were used. If the spots were produced by molds, single spore cultures were made as soon as the fungus sporulated.

The hymenomycetes were much more difficult to isolate. The plates were observed frequently, and as soon as the transfer grew sufficiently other plates were made from the mycelial growth around it. Great care was taken to avoid the mycelia of any molds which might be present. It is seldom indeed that a piece of pulp is infected with a hymenomycete without being also more or less infected with various molds, and vice versa. It is frequently necessary to make many transfers before microscopic examination shows a pure culture. Welcome exceptions were several hymenomycetes which produce oidia, chlamydospores, or basidiospores; from these, single spore cultures could be made almost as easily as from the molds.

In working for pure cultures of pulp fungi, the greatest difficulty was caused by an overrunning of the plates by rapidly growing molds before other fungi could start growth. The most troublesome of these molds were species of *Trichoderma* and *Mucor*, which accounted for the loss of hundreds of plates. Some species of the former genus were almost invariably present and in a sporulating condition on deteriorating pulp.

Although bacteria probably play some part in the decay of wood pulp, it is quite evident from the studies made that they are not as important a factor as might be expected. There are perhaps two good reasons why this is true. Most cellulose-dissolving bacteria require (1) an abundance of moisture, and (2) a slightly alkaline medium. Ordinary pulp storage conditions would not satisfy the first condition, and ground-wood and sulphite pulps, which are slightly acid, do not afford the second.

FUNGI OBSERVED

Although molds, by which term all fungi except the hymenomycetes are referred to here, are more numerous and occur more frequently, they cause much less damage to pulp than do hymenomycetes. When molds are present, however, hymenomycetes are very likely to be found.

The most common of all the fungi observed are molds with large, dark-brown mycelia which interlace the wood fibers and produce a neutral gray or olive-black blotch in the pulp. At times the infection spots coalesce, and large gray or blue-black areas are formed. Several species of fungi produce such spots, and it is impossible to distinguish between them except by cultural methods. Blotches pink to purple in hue are found less frequently. They are produced by species of *Penicillium* and *Fusarium*. Only rarely have these molds been found sporulating on the pulp. Large yellow blotches are frequent in occurrence, most of them being indicative of some species of *Trichoderma*. Pinkish cinnamon spots are quite common, and are caused either by a mold or by any of several wood-destroying fungi (hymenomycetes). It is often difficult to distinguish between the two types, especially in the early stages of infection. From small

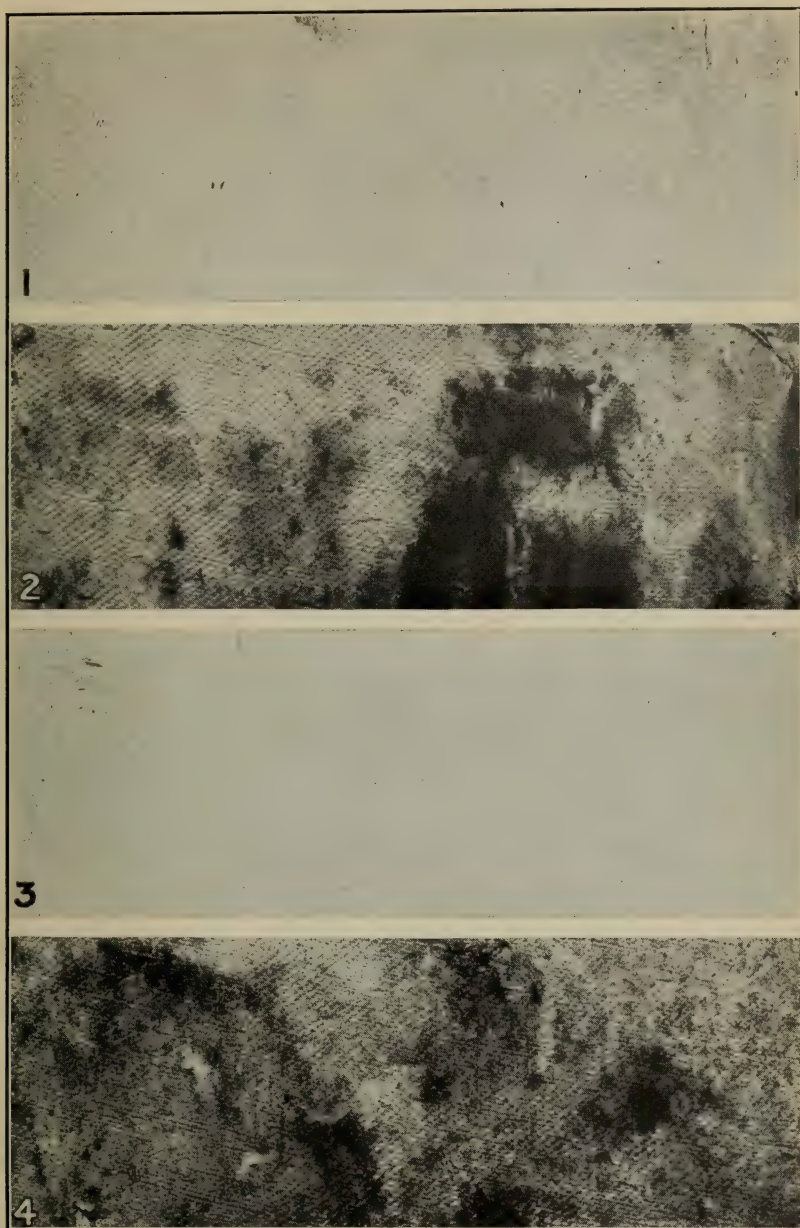
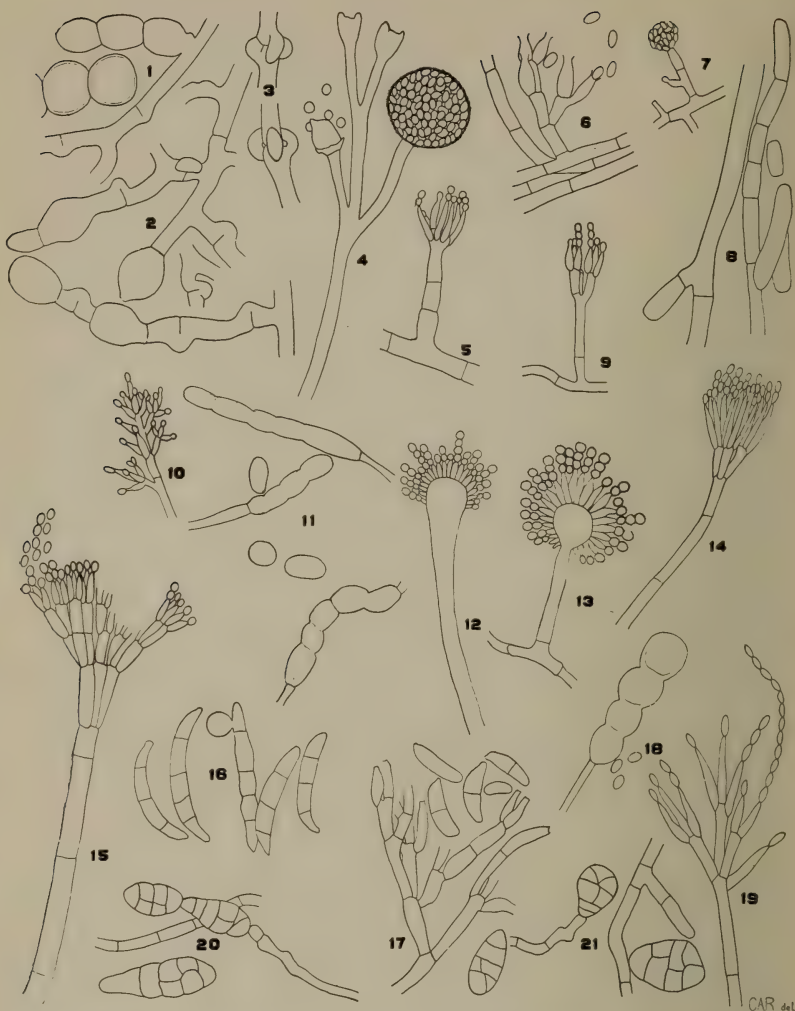


FIG. 1.—Section of small lap of ground-wood pulp treated with dry naphthalene at the rate of 50 pounds per ton of dry pulp and stored for 13½ months in pulp shed. Note clean condition under flakes of naphthalene and molded condition elsewhere

FIG. 2.—Section of commercial lap of ground-wood pulp sprayed with cymene at the rate of 2 pounds per ton of dry pulp and stored for 10 months in pulp shed. Note the severe molding

FIG. 3.—Section of commercial lap of ground-wood pulp sprayed with cymene and naphthalene mixture (50:50) at the rate of 4 pounds per ton of dry pulp. Stored for 10 months in pulp shed. Note perfect condition

FIG. 4.—Section of commercial lap of ground-wood pulp stored 10 months in pulp shed. Note the severe molding and decay



DRAWINGS OF REPRESENTATIVE FUNGI ISOLATED FROM WOOD PULP (X 120,
EXCEPT FIG. 4)

- FIGS. 1-3.—Mycelium and chlamydospores of hymenomycetes
 FIG. 4.—Sporangiophore of *Mucor plumbeus* (X 55)
 FIG. 5.—*Citromyces* sp., conidiophores and spores
 FIG. 6.—Culture 81318-1, conidiophores and spores
 FIG. 7.—*Trichoderma* sp., conidiophores and spores
 FIG. 8.—*Oidia* and mycelium of *Oidium* sp.
 FIG. 9.—*Penicillium* sp., conidiophores and spores
 FIG. 10.—*Verticillium* sp., conidiophores and spores
 FIG. 11.—Chlamydospores of *Torula* sp.
 FIG. 12.—*Aspergillus fumigatus*, conidiophores and spores

- FIG. 13.—*A. niger*, conidiophores and spores
 FIG. 14.—*Penicillium* sp., conidiophores and spores
 FIG. 15.—*Gliocladium* sp., conidiophores and spores
 FIG. 16.—Spores of *Fusarium* sp.
 FIG. 17.—*Fusarium* sp., conidiophores and spores
 FIG. 18.—Chlamydospores and microconidia of *Fusarium* sp. Spores and mycelium
 FIG. 19.—*Spicaria* sp., conidiophores and spores
 FIG. 20.—*Alternaria* sp., conidiophores and spores
 FIG. 21.—*Stemphylium* sp., conidiophores and spores

round brown spots, very commonly found, a species of *Alternaria* has been isolated consistently. Not all such spots, however, are produced by the same fungus.

Several of the molds commonly inhabiting pulp produce no pigment, have a colorless mycelia, and so are evident only when they sporulate. Among these were identified species of *Gliocladium*, *Penicillium*, *Citromyces*, *Trichoderma*, *Aspergillus*, and *Mucor*.

Brown blotches are produced by several species of molds and by some hymenomycetes. Generally speaking, the hymenomycetes produce areas of some shade of brown, varying from a faint pinkish cinnamon to a brown-black, though some produce cream-colored or bleached areas. The areas of pulp infected with hymenomycetes may be very weak. They may be much thinner than the surrounding portions of the pulp oftentimes falling out entirely when the pulp is moved.

Many of the cultures have not as yet been identified. Those isolated from pulp and water are listed as follows:

Phycomycetes

Mucoraceae

Mucor plumbeus Bon.

Mucor racemosus Fres.

Rhizopus nigricans Ehrenb.

Ascomycetes

Pezizaceae

Peziza repanda Wahl.¹

Mollisiaceae

Orbilia rubella Pers.¹

Sphaeriaceae

Chaetomium globosum Kunze¹

Chaetomium funicolum Cooke¹

Basidiomycetes

Hymenomycetes

Agaricaceae

Paxillus panuoides Fr.

15 unidentified cultures, discussed hereinafter.

Fungi imperfecti

Sphaerioidaceae

Cytospora sp.

Mucedinaceae

Torulopsis rosea Berl.

Oidium sp.

Papulospora nigra Hotson

Trichoderma spp. (11 cultures)

Aspergillus niger van Tiegh

Aspergillus fumigatus Fres. (2 cultures)¹

Aspergillus flavus group (2 cultures)¹

Penicillium pinophilum Hedge.¹

Penicillium purpurogenum O. Stoll¹

Penicillium brevicarule series¹

Penicillium commune Thom¹

Penicillium spp. (13 cultures)

Citromyces spp. (2 cultures)¹

¹ ACKNOWLEDGMENT.—The late Dr. E. J. Durand and Drs. A. H. Chivers, Charles Thom, and Margaret B. Church rendered aid in identifying these fungi.

Fungi imperfecti—Continued*Mucedinaceae*—Continued*Gliocladium* sp.*Verticillium* sp.*Spicaria* sp.Unidentified *Mucedinaceae* (1 culture)*Dematiaceae**Torula* sp.*Thielaviopsis* sp.*Stemphylium* sp.*Alternaria* spp. (2 cultures)Unidentified *Dematiaceae* (22 cultures)*Tuberculariaceae**Fusarium* spp. (9 cultures)

None of the hymenomycetes which are commonly found on pulp wood have been isolated from pulp, although the following species obtained from pulp wood or from boards taken from pulp sheds grew when planted on pulp: *Fomes roseus* Fr., *Lentinus lepideus* Fr., *Peniophora tabacina* Burt., *Stereum sanguinolentum* A. and S., *Corticium galactinum* Fr., and six undetermined species (cultures 4620-3, 4620-4, 61420-3, 61420-4, 61420-5, 61420-7). (See Table 16.)

DESCRIPTION OF CULTURES OBTAINED FROM PULP AND WATER

PHYCOMYCETES

MUCORACEAE

It is probable that several species of the Mucoraceae grow on pulp, but for the reasons that they seem to be superficial, do not produce a definite discoloration, and generally do not produce spores in numbers large enough to damage the pulp, little attention was given this group. Only three species, which occur frequently, have been isolated.

Mucor plumbeus Bon.—Mycelium submerged, hyaline; chlamydospores common, hyaline to light brown;⁵ sporangiophores upright, about 1 centimeter high, branches cymose or irregular, forming a hoary turf in young cultures; sporangia at first gray then olive black, walls very finely aculeated (Pl. XVI, fig. 4); columella cylindrical or pyriform, with one or more tapering or blunt spines on top; spores globose, light brown. Isolated from soda pulp. Very common on all kinds of pulp.

Mucor racemosus Fres.—Mycelium submerged, septate; chlamydospores frequent; sporangiophores upright, very short, 1 to 5 millimeters, septate, branched, cymose or irregular; sporangia small, white then blue-gray, walls very finely aculeated; columella hemispherical or short cylindrical; spores light brown. Isolated from ground wood. Common.

Rhizopus nigricans Ehrenb.—Aerial mycelium white, aseptate, becoming dark and septate in very old cultures; rhizoids numerous; sporangiphores fasciculate, erect, aseptate, arising from the nodes; sporangia globose, olive black; columella hemispherical; spores gray

⁵ Colors used in the following descriptions have, in most cases, been matched as closely as possible with Robert Ridgway's Color Standards and Color Nomenclature, 1912.

to brown, black en masse, subglobose or irregular. Isolated from soda pulp and ground wood (82219-10).⁶ Almost always present on damp pulp. This is the common black bread mold, which may be obtained at any time by exposing a culture plate or a moist piece of bread to the air.

ASCOMYCETES

PEZIZACEAE

Peziza repanda Wahl.—Mycelium white to cream colored, forming a rather thin, uneven layer over the agar, septate and colorless when growing in the pulp and causing no perceptible change in it; apothecia (fruit bodies) disk-shaped, cream-colored, 4 to 30 millimeters in diameter. Collected once from ground wood in a very wet place. Apothecia were also produced on the floor and shelves in the same pulp shed.

MOLLISACEAE

Orbilia rubella Pers.—Apothecia small, 1 to 3 millimeters, light pink. Collected once on a very rotten pulp. Not isolated.

SPHAERIACEAE

Chaetomium spp.—Mycelium hyaline, does not discolor the pulp, and apparently does little damage.

Chaetomium globosum Kunze—Culture gray; perithecia rather large; lateral hairs numerous, slender, slightly undulate, obscurely septate, minutely roughened, dark olive brown at base, lighter at tip; terminal hairs numerous, spreading and drooping, slender, aseptate, minutely roughened, dark olive brown with tapering yellow or hyaline tips, wavy. Spores olive brown, ovate, or subglobose. Isolated from sulphite pulp. Observed twice.

Chaetomium funicolum Cooke—Culture gray blue-green; perithecia smaller; lateral hairs few, straight, rigid, septate, tapering to collapsed tip, olive brown at base to hyaline at tip; terminal hairs profusely branched dichotomously, with branches reflexed, roughened, dark olive brown at base to hyaline at tips; spores light olive brown, ovate to lemon shaped. Isolated from ground wood. Observed once.

HYMENOMYCETES

AGARICACEAE

Paxillus panuoides Fr.—Mycelium white, becoming light cream with age, forming compact sheets over the surface of the medium. (See Pl. XVII, fig. 2.) In slant cultures, and sometimes in plate cultures, fairly large compact masses of hyphae are produced. The sporophores are more or less fan shaped, either sessile or with a very short lateral stipe. (See Pl. XVIII, figs. 1 and 2.) They are pure white on top when fresh, becoming yellowish with age, yellowish brown below. The spores are yellowish brown. This is one of the hymenomycetes which produces "red rust" or "red rot" in pulp. It is the only one found on this occasion producing sporophores on pulp. It colors the pulp pinkish buff or cinnamon buff to cinnamon (dry),

⁶ The culture numbers are given for those fungi which were used to obtain the data shown in Tables 13, 14, 15, 16, and 17.

or mikado brown to russet (wet). Pulp infected with this fungus becomes very brittle. Isolated from "red-rusted" pulp, later from a sporophore which developed on the same lot of pulp when placed in a sterile Wardian case. This is the only hymenomycete which was found producing a fruit body. A very common species.

UNIDENTIFIED HYMENOMYCETES

In the absence of fruit bodies, which (with the exception above noted) the investigators were unable to find on pulp or to develop in culture, there is no way by which cultures of hymenomycetes may be identified except by comparison with cultures of known fungi. Although these species were compared with large numbers of known hymenomycetes in pure cultures, none was definitely identified. For convenience they will be grouped as follows:

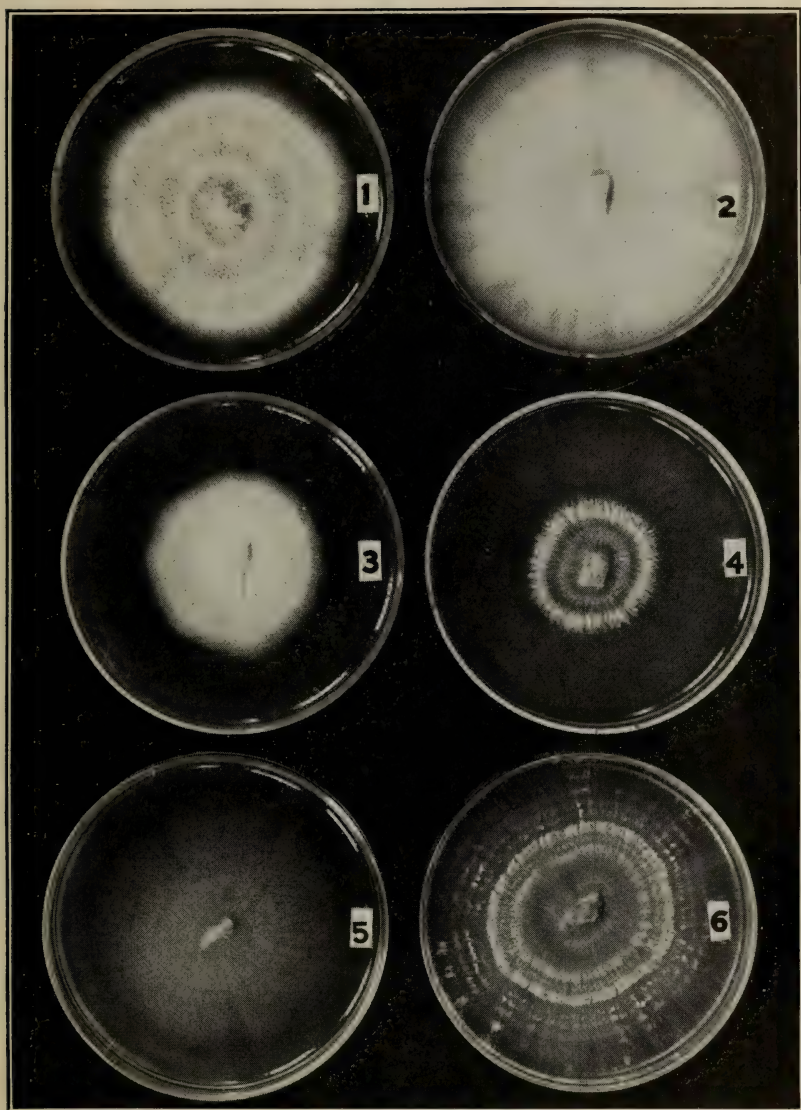
1. Four cultures varying but slightly; mycelium soggy, appressed, forming compact sheets over the agar; large, conspicuous clamps; barrel-shaped or globose interstitial and terminal chlamydospores (Pl. XVI, fig. 1), in more or less regular zones in Petri dish cultures, white or cream colored, narrow or wide (Pl. XVII, figs. 4 and 6). These fungi bleach pulp somewhat, but are not vigorous wood destroyers. Isolated from ground-wood (10918-10, 102019-1a, 6320-1) and sulphite pulp. Very common.

2. One culture; mycelium soggy, appressed; differs from 1 in that the mycelium does not form such compact sheets over the agar; chlamydospores in more or less distinct radiating lines. (See Pl. XVII, fig. 5.) In older cultures small white tufts of mycelium appear, scattered sometimes over the surface, but more frequently around the edge of the plate. In jar cultures, and sometimes in slants, dense masses of chlamydospores are formed on the surface of the glass. (See Pl. XIX, fig. 1.) Chlamydospores barrel shaped, ellipsoid, or somewhat lemon shaped, terminal or intercalary. Clamps conspicuous. (See Pl. XVI, fig. 2.) Areas are cream-colored when freshly infected, but become pinkish buff (dry) to clay color (wet), buffy brown (dry) to olive brown (wet), and finally mummy brown (dry) to dark clove brown (wet). This fungus causes great damage which, in severe infections, may become an entire loss, the pulp becoming so brittle that it can not be used. (See Pl. XIX.) Isolated from ground wood (82219-15). Common on ground wood and observed once on sulphite pulp.

3. Two cultures very nearly alike; mycelium soggy, appressed; chlamydospores in creamy masses or in small white mealy specks. Newly infected areas cream-colored, later pinkish buff (dry) to cinnamon buff (wet), tawny olive (dry) to Chaetura black (wet). Infected pulp very friable, useless. Isolated from ground wood (4620-1, 4620-2). Common.

4. One culture; mycelium appressed, soggy, forming compact sheet; clamps conspicuous; no chlamydospores. Does not discolor the pulp and causes very little damage. Isolated from sulphite pulp (6920-2). Observed once.

5. One culture; mycelium appressed, soggy, forming compact sheets over surface of plates, with here and there fluffy white bunches of mycelium; clamps conspicuous; maize yellow, ellipsoid or globose chlamydospores produced on surface, forming a yellow mealy mass.



PETRI-DISH CULTURES OF HYMENOMYCETES ISOLATED FROM GROUND-
WOOD PULP

FIGS. 1-5.—Ten-day-old growth:

FIG. 1.—Culture No. 92219-4

FIG. 2.—*Parillus panuoides*

FIG. 3.—Culture No. 82219-13

FIG. 4.—Culture No. 102019-1a

FIG. 5.—Culture No. 82219-15

FIG. 6.—Twenty-four-day-old growth of culture No. 102019-1a (cf. fig. 4)

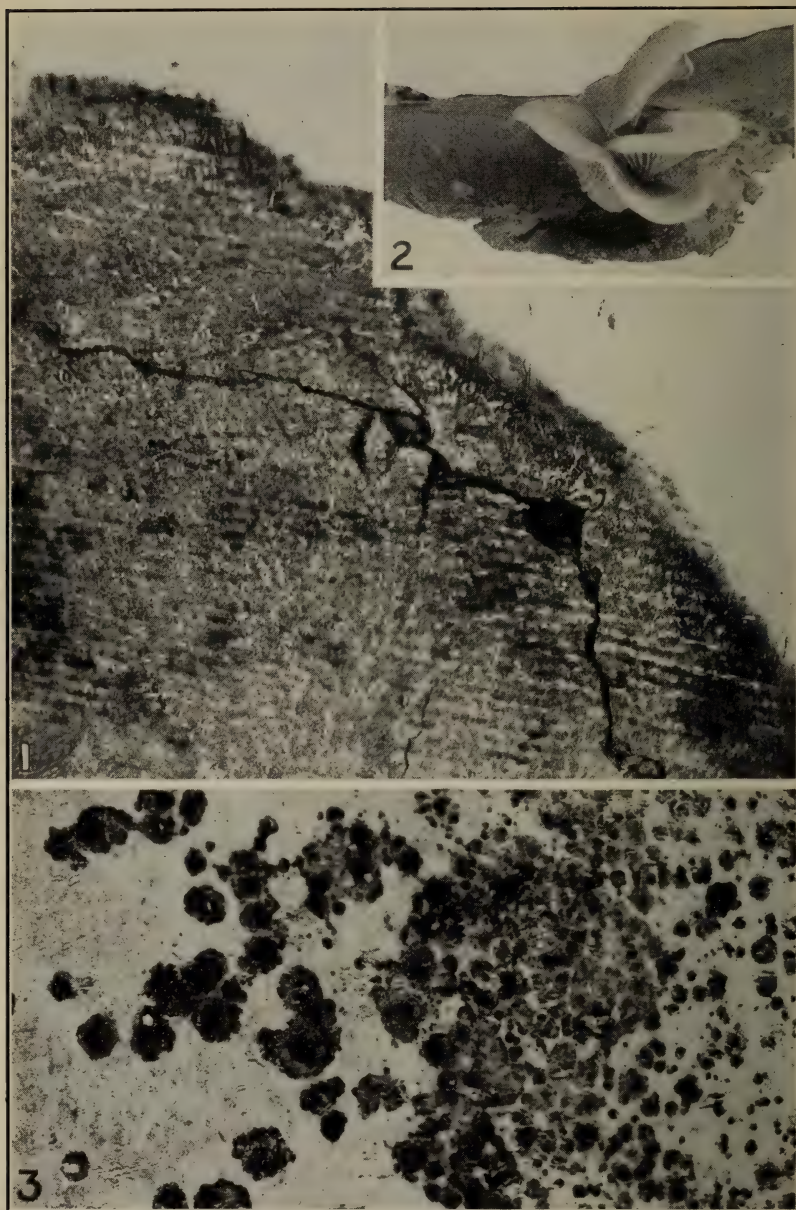


FIG. 1.—Portion of a lap of ground-wood pulp rotted by *Pazillus pannuoides* during a six months' storage period in the basement of a New York mill. This type of rot is frequently termed "red rust."

FIG. 2.—Fruit bodies of *Pazillus pannuoides* developed at the laboratory from the samples of "red-rusted" pulp shown in fig. 1

FIG. 3.—Ground-wood pulp severely molded during six months' storage in the basement of the mill referred to under fig. 1

Pulp is not discolored by this fungus, except that the yellow chlamydospores are formed on the surface. It causes little damage. Isolated from ground wood (61520-1). Observed once.

6. One culture forming a loose silky layer over the surface of medium and a very fluffy white margin. In old cultures the mycelium sometimes becomes cinnamon colored. Glistening droplets appear on the mycelium. White to cinnamon buff, warty hymenial patches are frequently formed on plate cultures. This fungus turns the pulp pinkish buff (dry) to cinnamon buff (wet). It causes considerable loss in weight and makes the pulp very brittle. Isolated from ground wood (61020-1). A similar culture was isolated from spruce pulp wood. Observed once on pulp.

7. One culture with loose, fluffy mycelium, white, later becoming tinged cinnamon buff; no clamps; no chlamydospores. Macroscopically this culture has all the characteristics of a hymenomycete. Infected areas become pinkish buff (dry) to clay color (wet), with scattered depressed white spots. It causes considerable loss in weight in the pulp. Isolated from white water (62220-1). Observed once.

8. One culture with loose, fluffy, white mycelium, later becoming cinnamon buff. Some hyphæ are very large, with whorls of large clamps (Pl. XVI, fig. 3); no chlamydospores. Bleaches the agar.⁷ Newly infected areas are pinkish buff (wet), later becoming deep mikado brown. Isolated from fresh river water. Observed once.

9. Two cultures of a loose, fluffy, white fungus, which on Petri-dish cultures produces rather compact zones of basidia bearing basidiospores. (See Pl. XVII, fig. 1.) There is only a very slight difference between the two cultures, and they are probably two strains of the same species. Conspicuous clamps; chlamydospores. These fungi turn the pulp light ochraceous buff (dry) or ochraceous tawny (wet). A fine mottling with white depressed spots is noticeable in the older infected areas. These fungi cause considerable loss. Isolated from ground wood (82219-4, 6920-1). Common.

10. One culture producing long, fine, white radiating mycelial strands. (See Pl. XVII, fig. 3.) It produces brown sclerotia-like bodies. Conspicuous clamps; no chlamydospores. This fungus produces no discoloration of the pulp, but its presence is made evident by the long, glistening loose strands of mycelium found on opening up a lap of pulp infected with it, and by the sclerotia-like bodies. It causes only slight loss of weight in the pulp. Isolated from ground wood (82219-13). Common on ground wood, and observed once on sulphite pulp.

FUNGI IMPERFECTI

SPHAERIOIDACEAE

Cytospora sp.—Culture at first white, with scanty mycelium gathered in bunches, later becoming deep slate olive, reverse black; hyphæ hyaline to deep brown; sharply defined stroma containing several pycnidia; conidia hyaline, allantoid, minute. Agar normal; pulp deep blue-slate-black. Isolated from sulphite pulp. Rather common.

⁷ All culture characters given are those present when the fungi are grown on plain malt-bacto agar.

MUCEDINACEAE

Torulopsis rosea Berl.—Hyphæ obsolete; cells ellipsoid or globose, rose-colored en masse, usually budding at the ends, seldom forming chains. Agar normal; pulp slightly pink. Isolated from ground wood. Common.

Oidium sp.—Cultures wet and mucilaginous, occasionally mealy; septate hyphæ irregularly branched, more distinct than is usual in *Oidium*, but they break up into typical oidia (simple segmentation of the hyphæ). The oidia vary considerably in length; are at first cylindrical, but when separated become rounded at the ends. (See Pl. XVI, fig. 8.) This fungus causes little damage to the pulp. Infected areas are generally lighter in color than normal pulp. This fungus is probably responsible in part for pulp in very wet condition souring. Isolated from ground wood (62020-1). Common.

Papulospora nigra Hotson.—Mycelium scanty, white, becoming dirty gray in very old cultures, clamp connections conspicuous; bulbils colorless when young, becoming dark brown, then black, at maturity (Pl. XX, fig. 1), produced in large numbers, soon making entire culture appear black. No other means of reproduction known. The clamps indicate the relation of this species to the hymenomycetes. Hyaline mycelium penetrates the pulp; black bulbils are produced on surface. Isolated from ground wood (32019-7). Rather common.

Trichoderma spp.—Nine cultures varying enough to be of distinct species were isolated. Mycelium scanty, cottony, white or yellow, or compact, soggy, appressed, cream-colored to yellow; conidia in heads at tips of the many branches of the fertile hyphæ (Pl. XVI, fig. 7), scattered uniformly over surface, in small or large patches, or around the margin; conidia white, bluish gray, or reed-yellow to light or dark American green. Agar normal, yellowed, or browned; infected pulp normal in color, yellow or green. These species produce large masses of spores, most of which are American green, and make the pulp "dirty." Some cultures dissolve cellulose. Isolated from ground wood (82219-10, 32019-1), from sulphite pulp, from river water (6520-2). All very common.

Trichoderma sp.—Mycelium scanty, white, rapidly covering the surface of the agar; small, white, compact bunches of conidiophores, appearing early, scattered over the surface. As conidia mature these patches become pinkish cinnamon and, finally, cinnamon. This fungus causes a slight browning of the pulp. Isolated from ground wood (10918-4). Observed twice.

Aspergillus spp.⁸—This group produces globose conidia in chains at the tips of sterigmata, which in turn are born on the inflated heads of the fertile hyphæ. (See Pl. XVI, figs. 12 and 13.) None of the species discolor pulp, but all sporulate abundantly on the surface.

Aspergillus niger van Tiegh.—Mycelium scanty, superficial; but next to the glass, in slant culture, there is often a naphthalene yellow or citron-yellow sheet. The surface of cultures is soon covered with a coal-black, powdery mass, formed by conidia. Isolated from bleached sulphite and soda pulp. Very common. It is almost invariably present in the "sooty" blotches on pulp.

⁸ *Aspergillus* and *Penicillium* should properly be classed with the ascomycetes, but since the ascigerous stage is known for only a few, they are often placed with the fungi imperfecti.

Aspergillus fumigatus Fres.—(1) Mycelium sparse, superficial, white; entire surface covered with dark bluish gray-green spores which become deep slate olive in old cultures. Agar greenish yellow. This fungus dissolves cellulose. Isolated from river water (6520-1) Common. (2) No superficial mycelium; entire surface covered with dark bluish-gray conidia which become deep slate olive in old cultures. Agar purple-brown. Isolated from sulphite pulp. Common.

Aspergillus flavus group.—(1) No superficial mycelium; surface covered with parrot-green conidia which later become brownish olive. Isolated from sulphite pulp. Common. (2) Mycelium loose, fluffy, white, around the margin of young cultures, but soon covered with mignonette-green conidia which become brownish olive in very old cultures. Isolated from bleached sulphite. Common.

Penicillium spp.—Conidia globose or ellipsoid, borne in chains on the tips of sterigmata, which are small branchlets at the top of the unequally verticillately branched, uninflated fertile hyphæ. (See Pl. XVI, figs. 9 and 14.) Some of the species discolor the pulp; all of them produce spores in sufficient numbers to make the pulp "dirty." The species isolated may be described briefly as follows:

Penicillium brevicaulis group.—Mycelium scanty, appressed, soon covered with pinkish buff to avellaneous conidia, which later become cinnamon brown. Agar slightly darkened; pulp not discolored. Isolated from ground wood (81318-2). Common.

Penicillium divaricatum group.—Mycelium scanty, superficial, soon covered by a smooth layer of conidiophores with light brownish-olive conidia. Agar very dark brown; pulp slightly browned. Isolated from ground wood. Common.

Penicillium pinophilum Hedge.—Mycelium scanty, superficial when grown on malt agar. Cultures soon become dark bluish glaucous mixed with a little yellow-green due to conidia. Agar dark red; pulp pink to red. Seldom produces large numbers of spores on pulp, but the reddening is sufficient to give an off-color paper. According to Thom (26) it produces orange to red stains in pine wood. Isolated from ground wood (112217). Very common.

Penicillium purpurogenum O. Stoll.—Similar to *P. pinophilum* when grown on malt agar, but no yellow present in the spore surface, which is somewhat smoother. Agar red to purplish vinaceous in old cultures; pulp pink to purplish red. Isolated from ground wood (10918-11) and sulphite pulp. Very common.

Penicillium commune Thom.—Mycelium scanty, soon covered with celandine-green conidia, which become gnaphalium green or even dark olive. Older cultures more or less overgrown with white floccose mycelium. Agar and pulp normal. Isolated from ground wood (10918-3). Common.

Undetermined Penicillium species.—Nine cultures, varying enough to be distinct species, were isolated. Mycelium soggy, appressed, or cottony; floccose, scanty, or abundant; white, reed yellow, or colonial buff; conidia bluish gray-green, grayish blue-green, pistachio green, glaucous, citron or glass green to light brownish olive, ecru olive, mytho, dark ivy, or dark American green; surface dry, or covered with droplets of clear, amber, or pink liquid. Agar normal, yellow, green, or brown; pulp normal or slightly browned. One culture dissolves cellulose. Isolated from ground wood (10918-9, 82219-12), sulphite pulp, soda pulp, and river water (6520-3). All very common.

Two cultures similar to *P. pinophilum* but both producing black sclerotia-like bodies. Conidial surface as in *P. pinophilum*, or glass green to tea green. Agar red; pulp pink to red. Isolated from sulphite pulp. Each observed once.

One culture with mycelium white to cream-colored, cottony, soon covered with white ascigerous masses, conidial fructifications rather rare. Agar normal; pulp slightly browned. Isolated from ground wood. Observed once.

Citromyces sp.—Macroscopically appears like *Penicillium*, but distinguished by the somewhat inflated conidiophores bearing a single whorl of sterigmata. (See Pl. XVI, fig. 5.) Mycelium scanty, white, or soggy, appressed; conidia deep bluish gray-green, or deep glaucous gray. Agar normal or yellowish; pulp made "dirty" by spores. Isolated from ground wood (10918-6, 10918-12). Common.

Gliocladium sp.—Mycelium very scanty, loosely floccose; conidiophores *Penicillium*-like (Pl. XVI, fig. 15), except that they are widely scattered over the surface of the cultures so that no solid mass of them is found. Spores held in a deep American green mucus which is soluble in water and sometimes is produced in such amounts that the pulp becomes dyed with it. Isolated from ground wood (10918-1) and sulphite pulp. Very common in all kinds of pulp and river water.

Verticillium sp.—Mycelium sparse, superficial, hyaline or very light brown, soon covered with cinnamon-drab conidia borne singly at tips of loose verticillately branched conidiophores (Pl. XVI, fig. 10); conidia held together in heads. Pulp slightly browned. Isolated from ground wood. Common.

Spicaria sp.—Mycelium appressed, soon covered with white to cinnamon-buff fructifications. The conidiophores are branched in loose verticils (Pl. XVI, fig. 19), thus differing from *Penicillium*, which has close verticils. Underside of culture is brown, and in older cultures the agar becomes dark brown. Pulp browned. Isolated from ground wood (10918-5). Observed once.

Unidentified Mucedinaceae.—Several other *Mucedinaceae* were isolated from pulp, but since they caused no perceptible damage and were not common, notes on them are omitted from this report. One species which caused a yellowing of the pulp is described as follows: Culture deep colonial buff to tawny, appressed to downy; hyphæ hyaline to yellowish; some large, rigid, light yellow-brown filaments in clusters; many cylindrical oidia of various lengths. Agar and pulp, colonial buff to tawny. Isolated from sulphite pulp. Common.

DEMATIACEAE

Torula sp.—Hyphæ hyaline, soon becoming very dark brown, mostly submerged, breaking up into chains of one-celled, dark-brown spores. Pulp very dark neutral gray. (See Pl. XVI, fig. 11.) Isolated from sulphite pulp. Common on sulphite and ground-wood pulps.

Thielaviopsis sp.—Culture dull black, appressed, with white powdery masses on surface; hyphæ hyaline, then brown, breaking up into chains of one-celled, dark-brown chlamydospores; many hyaline, oidia-like conidia produced endogenously. Agar normal; pulp gray. Isolated from ground wood. Observed once.

Stemphylium sp.—Culture green-black, reverse jet-black; mycelium decumbent, hyaline to brown, scanty; conidiophores decumbent, irregularly branched; conidia large, muriform, very dark brown, mostly ovoid. (See Pl. XVI, fig. 21.) The brown hyphæ intertwine the fibers, producing olive-black areas in the infected pulp. The large, dark spores are frequently found in “sooty” spots. Isolated from soda pulp. Common.

Alternaria sp.—Culture velvety, pale to deep olive gray, reverse black; mycelium hyaline to brown; conidia obclavate, muriform, brown, single or in chains (12 spores have been observed in one chain) at the ends of conidiophores which vary but little from the regular hyphæ (Pl. XVI, fig. 20); chains sometimes branched. This species produces small, round, brown spots in ground wood. Isolated from ground wood (32019-2). Common.

Unidentified Dematiaceae.—Mycelium hyaline becoming brown, often in heavy decumbent strands.

1. Cultures dark olive gray or grayish olive to mouse gray, reverse black; conidiophores short, rarely branched, brown at base to subhyaline or hyaline at roughened tip (Pl. XX, fig. 2); conidia fusoid or ellipsoid, subhyaline to hyaline. Agar red-brown or normal; pulp gray. Isolated from ground wood (3818-1, 82219-5). Very common.

2. Cultures mouse gray, drab, or dark snuff brown, reverse brown-black; mycelium downy, cottony, or fluffy to feltlike; conidiophores branched or unbranched, lateral branches of ordinary hyphæ, hyaline to light brown, ends open to form a “collar” which is slightly flaring (Pl. XVI, fig. 6) and concolorous with conidiophore, bell shaped and dark brown (Pl. XX, fig. 3) or widely flaring, saucer shaped and dark brown (Pl. XX, fig. 4). Conidia borne singly at tips of conidiophores, held together in heads; hyaline, subhyaline, or light brown; ovoid, ellipsoid, or globose. Agar normal or bleached; pulp dark neutral gray, olive gray, or brown-black. Isolated from ground-wood (81318-1, 10910-7, 82219-18, 82219-2) and sulphite pulp. Very common.

3. Cultures olive brown to black, or mouse gray to dark grayish olive, reverse black; hyphæ dark brown, frequently coiled; conidiophores *Penicillium*-like, dark brown at base to hyaline at tips of final branches; conidia globose, small, hyaline, borne in chains at tips of conidiophores. Agar normal; pulp dark neutral gray. Isolated from ground-wood (82219-9, 82219-23) and sulphite pulp. Very common.

4. Culture soggy, appressed, cream to cinnamon; hyphæ hyaline; conidiophores short, rigid, septate, brown below branches, branched irregularly, tips hyaline; conidia hyaline, ovoid or ellipsoid, borne in short chains at tips of conidiophores. Agar normal; pulp cinnamon. Isolated from sulphite pulp. Rather common.

5. Cultures deep olive gray, reverse brown; mycelium hyaline or brown, sometimes in strands, not superficial; conidiophores short, rigid, brown at base, hyaline toward tips, branched in irregular whorls; conidia oidia-like, in chains at tips of conidiophores, hyaline. Agar slightly darkened; pulp olive gray. Isolated from sulphite pulp. Common.

TUBERCULARIACEAE

Fusarium sp.—Mycelium scanty, hyaline to light brown; chlamydospores brown, rough, globose; conidia mostly one or two celled. (See Pl. XVI, fig. 17.) Agar red; pulp orange vinaceous. Isolated from sulphite pulp. Observed once.

Fusarium sp.—Mycelium scanty, pinkish; no chlamydospores; sporodochia small, discoid, Mars brown; conidia one to five celled. Agar slightly purple; pulp deep purplish vinaceous. Isolated from sulphite pulp and ground-wood. Observed twice.

Fusarium sp.—Mycelium very scanty, white, no chlamydospores; sporodochia cream, light Terre Verte to neutral red; conidia mostly five celled, very few one celled. (See Pl. XVI, fig. 16.) Agar slightly red; pulp deep purplish vinaceous. Isolated from ground-wood. Observed once.

Fusarium sp.—Cultures mealy to subgelatinous, from white to pale cinnamon pink; hyphæ hyaline; numerous pink intercalary chlamydospores; spores abundant, small, ovoid, hyaline, apparently produced in clumps at ends of branches (Pl. XVI, fig. 18); very few typical *Fusarium* spores found; no well-defined sporodochia. Agar normal, pulp light pinkish cinnamon. Isolated from ground-wood (82219-1) and sulphite pulp. Very common.

CLASSIFICATION OF ORGANISMS BASED ON COLOR CHANGES IN PULP

The fungi just described have been grouped according to their morphology, which is the true mycological classification. In the following key the fungi are grouped according to their color reaction on pulp. This key is an attempt to present the fungi in such a way that those least familiar with them may be able to determine which organisms may be present and thus to decide whether an organism is a hymenomycete, causing a loss in the wood fiber, or a mold, producing simply a discoloration of the pulp. Each of the fungi investigated either (a) bleaches pulp, (b) causes no color change in the pulp, (c) produces a color change which may be due either to chemical disintegration of the pulp itself or to pigments produced by the fungi, or (d) produces a color change which is due to the colored mycelia which are scattered through the pulp. The key classifies the fungi described above according to these color effects, as follows:

Organisms that bleach pulp.

Producing no superficial spores.

Hymenomycetes, *Oidium* sp.

Organisms that cause no color change in pulp.

Producing no superficial spores.

Hymenomycetes.

Producing superficial spores.

Spores maize yellow.

Hymenomycetes.

Spores green or blue.

Trichoderma spp., *Aspergillus* spp., *Penicillium* spp., *Citromyces* spp., *Gliocladium* sp.

Spores black.

Papulospora nigra, *Aspergillus niger*.

Spores brown.

Trichoderma sp., *Penicillium* sp., *Verticillium* sp.

Producing superficial ascocarps (fruit bodies).

Asci in apothecia (open, saucer shaped).

Peziza repanda, *Orbilia rubella*.

Asci in perithecia (nearly closed, globose).

Chaetomium globosum, *Chaetomium funiculum*.

Organisms that cause spots in pulp not due to colored mycelia.

Producing no superficial spores.

Pulp some shade of buff, brown, or black.

Hymenomyces.

Pulp pale pink.

Torulopsis rosea.

Producing superficial spores.

Pulp some shade of red.

Penicillium spp., *Fusarium* spp.

Pulp some shade of yellow or green.

Trichoderma spp., unidentified Mucedinaceae.

Pulp some shade of brown.

Trichoderma sp., *Penicillium* sp., *Spicaria* sp.

Organisms that cause spots in pulp, due in part at least to colored mycelia.

Pulp light brown.

Verticillium sp.

Pulp dark brown.

Alternaria sp., unidentified Dematiaceae.

Pulp some shade of gray.

Torula sp., *Thielaviopsis* sp., unidentified Dematiaceae.

Pulp blue-slate-black.

Cytospora sp.

Pulp olive black.

Stemphylium sp.

PHYSICAL AND CHEMICAL PROPERTIES OF GROUND-WOOD PULP DETERIORATED BY SPECIFIC FUNGI IN PURE CULTURES

PHYSICAL PROPERTIES

PREPARATION AND EXAMINATION OF SAMPLES

The series of tests to determine the specific action on pulp of various fungi in pure culture was comprehensive in scope, representing about half of the species isolated. The test medium was fresh, clean ground wood made up of spruce, 70 per cent, and balsam, 30 per cent. The pulp was cut up into pieces $2\frac{1}{2}$ by 10 inches, all of which were oven dried (100 to 105° C.) and weighed, then soaked in distilled water, folded twice, and tied with thread. The culture chambers used were 2-quart fruit jars, which were prepared as follows: A piece of galvanized screen, $2\frac{1}{4}$ by $5\frac{1}{2}$ inches, was bent down 1 inch from each end; this was placed in the bottom of the jar, and 100 cubic centimeters of distilled water were poured in. Three pieces of pulp, weighing 90 to 100 grams in all, were then placed in the jar on the screen, which supported them above the water. (See Pl. XIX, fig. 1.) A small extra piece of pulp, to be used for cultures and color comparisons at the end of the experiment, was placed in each jar, in close contact with the other samples in order to insure infection. The jars were then capped with a layer of cloth, a layer of cotton, then the top piece of the can lid, and finally with a layer of cloth over all. Two large rubber bands were used to fasten the cap in place. The jars were then sterilized by steaming in an autoclave at 100° C. for one hour on each of three successive days. After the

last sterilization they were transferred immediately from the autoclave to the inoculating case, in which they were allowed to cool.

Sets of three jars each were inoculated with a pure culture of a fungus that had been isolated from pulp, pulp-wood, boards from pulp sheds, or river water. The following two methods of inoculation were used:

1. In the case of molds, a sporulating culture on a malt agar slant was used as the source of the inoculum. Five cubic centimeters of sterilized distilled water were poured into the culture tube, which was thoroughly shaken until a heavy spore suspension was obtained. Then three test tubes containing sterile water were opened and a third of the spore suspension was poured into each. The three spore suspensions resulting were then used to inoculate the pulp samples. One side of the jar cover was carefully lifted and the spore suspension poured over the tops of the pieces of pulp in the jar. Care was exerted to have the inoculation of the pieces of pulp as nearly uniform as possible, so as to establish a check.

2. The cultures inoculated with wood destroyers were treated as follows: Petri-dish cultures of the fungus in question were made on malt agar a week in advance, after which time they were cut into pieces about 8 millimeters square, and one square was placed on the top of each of the three pieces of pulp in the jar. The jars, as inoculated, were removed from the culture case. New rubber bands were substituted for the old ones, and white papers, to keep the dust from the caps, were placed over the tops and held in place by heavy rubber bands.

All the jars were then stored in an inside basement room in which the temperature was fairly constant (average 21° C.). The three jars of each set were opened at the end of 6, 9, and 12 months, respectively. At the end of the test the moisture content of the samples was determined, and the loss, based on oven-dry (100 to 105° C.) weight, was obtained for each culture. As each jar was opened the small extra piece of pulp was transferred to a sterile Petri dish and small pieces of it were then planted upon malt agar plates. The object of this procedure was to determine whether or not the fungus had remained viable throughout the experiment and whether the culture had remained pure. Results in these respects were positive except in the cases specially noted in the tables.

DATA AND DISCUSSION

Table 14 gives the results obtained with 29 cultures of molds, representing at least 26 distinct species. The loss in weight was small in all the mold-inoculated pulps. *Trichoderma* sp. (6520-2) caused the greatest loss in 12 months, 3.2 per cent. Four samples became some shade of pink, and nine became gray. Only three samples, which were gray, were dark enough to have spoiled the quality of paper made from them. The remaining 16 samples were recorded as "normal," which means that (1) the pulp itself retained its usual color; (2) the fungus did not make the pulp brittle, or, in so far as could be determined macroscopically, otherwise change its physical properties; and (3) the colored spores of the fungus, produced on the surface of the pulp, were in sufficiently small numbers and of such kind that they would ordinarily be washed off in the beater without causing any damage to the manufactured paper.

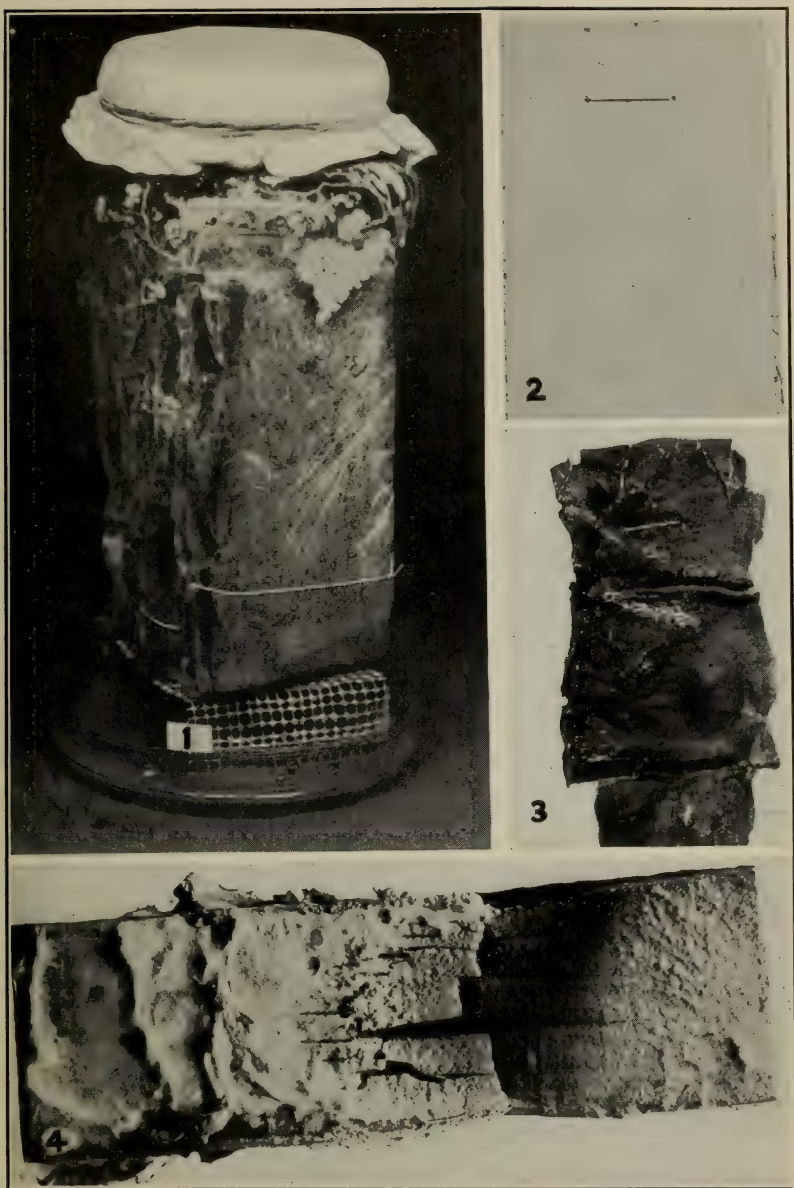
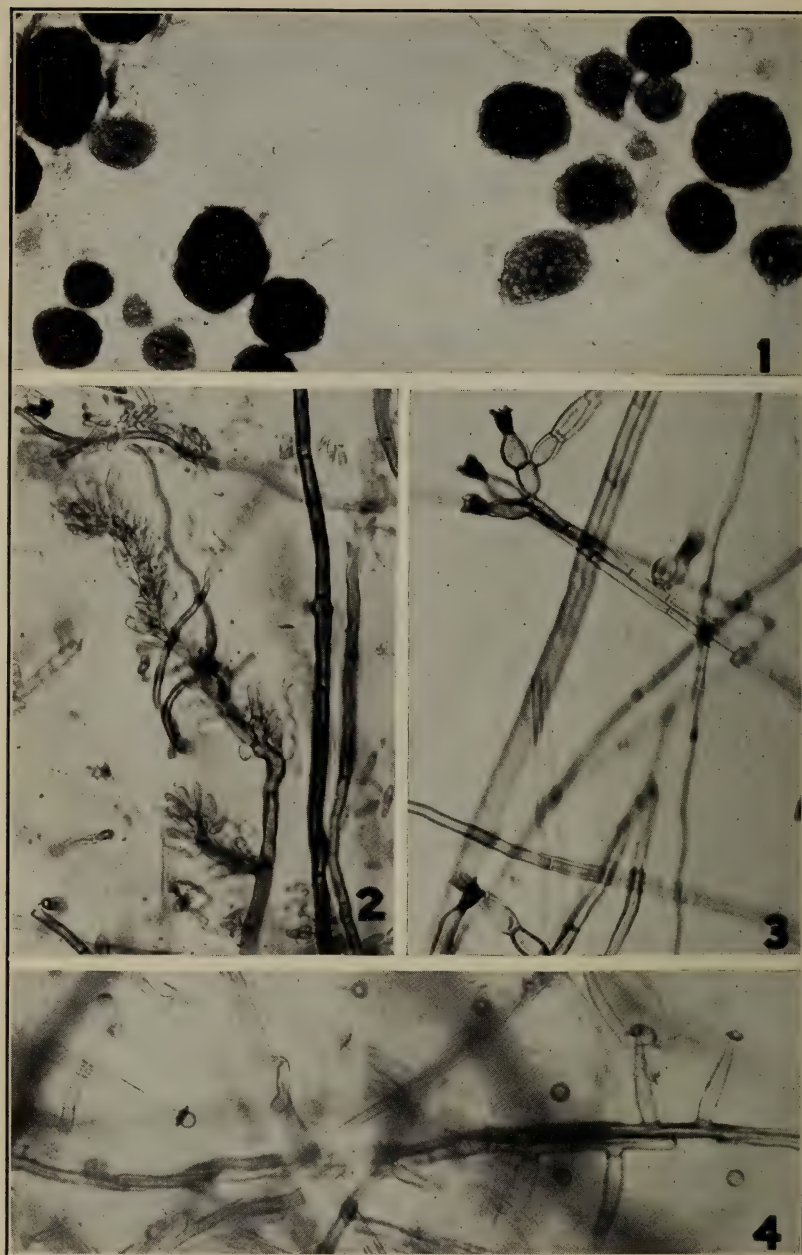


FIG. 1.—Nine-months-old pure culture of pulp infected with a wood-destroying fungus, culture No. 82219-15, sample No. 25

FIG. 2.—Clean pulp

FIG. 3.—Piece of pulp, similar to fig. 2 originally, after infection for six months with culture No. 82219-15

FIG. 4.—Block of white spruce wood completely rotted in six months by same fungus



REPRESENTATIVE MOLDS ISOLATED FROM GROUND-WOOD PULP

FIG. 1.—Bulbils of *Papulospora nigra* (X 150)

FIG. 2.—Conidiophores, spores, and mycelium of an unidentified species of *Dematiaceae*, culture No. 3818-1 (X 750)

FIG. 3.—Conidiophores and mycelium of an unidentified species of *Dematiaceae*, culture No. 10918-7 (X 750)

FIG. 4.—Conidiophores, spores, and mycelium of an unidentified species of *Dematiaceae*, culture No. 92219-2 (X 750)

Although at the outset care was taken to bring the pulp in the tests to a uniform condition of moisture the tables show that at the end the individual samples varied considerably, ranging from 53.6 to 73.3 per cent in moisture content. The average was 65 per cent, as compared with the approximately 70 per cent which pulp normally has when taken from the wet machines.

Table 15 gives the results obtained with 13 species of hymenomyces—12 isolated from ground wood, and one (6920-2) from sulphite pulp. It will be noted that the figures recorded in Table 15 show results quite different from those in Table 14. Seven organisms caused sufficient color changes in the pulp to have appreciably discolored any paper manufactured from it. Five fungi made the infected pulp more or less brittle, and three caused it to become friable to the point of entire worthlessness. The most destructive of these organisms are those which are found most frequently on ground-wood.

The moisture content of the pulp samples at the end of these tests was somewhat higher, averaging 68.7 per cent, than in the tests made with the molds, although efforts were made to start all exactly alike. The condition may be accounted for in some cases by the fungus growing down into the water in the bottom of the jar, whence it conducted moisture to the pulp. All but two of the cultures remained viable until the end of 12 months. The two that died are not classed as vigorous wood destroyers.

TABLE 14.—*Deterioration of ground wood caused by 29 cultures of molds isolated from pulp and water*

Sample No.	Culture No.	Organism	Per cent moisture	Per cent loss in weight after—			Physical condition of pulp
				6 months	9 months	12 months	
196	Uninoculated		67.3	0.5	(1)	0.6	Normal.
197			69.0	1.0			
198			61.1		1.0		
88	82219-11	<i>Mucor</i> sp.	63.8			.8	Do.
89			66.6	.8			
90			65.1		.8		
181	62020-1	<i>Oidium</i> sp.	64.3			1.4	Do.
182				.3			
183			64.1		.3		
65	32019-1	<i>Trichoderma</i> sp.	57.6			1.0	Do.
64			66.8	.5			
66			61.0		1.0		
85	82219-10	do.	62.0			1.2	Do.
86			66.4	1.8			
87			63.6		1.6		
190	6520-2 ²	do.	72.6			3.2	Do.
192			72.7	1.2			
191			68.4		1.1		
112	82219-6	<i>Fusarium</i> sp.	58.1			1.1	Very slight pink.
113			64.7	1.6			
114			71.2		1.4		
187	6520-1 ¹	<i>Aspergillus fumigatus</i>	73.3			3.0	Normal.
188				.4			
189			68.9		1.0		
16	81318-2	<i>Penicillium</i> sp.	59.0			.6	Do.
17				1.8			
18			67.8		1.5		
19	10918-9	do.	60.5			1.5	Do.
20				.9			
33			67.8		1.8		
37	10918-3	do.	63.4			2.0	Do.
38							
39							

¹ Contaminated with *Penicillium* sp.

² Isolated from water.

TABLE 14.—*Deterioration of ground wood caused by 29 cultures of molds isolated from pulp and water—Continued*

Sample No.	Culture No.	Organism	Per cent moisture	Per cent loss in weight after—			Physical condition of pulp
				6 months	9 months	12 months	
52	10918-11	<i>Penicillium purpogenum</i> .	66.1	0.8			Pinkish.
53			66.8		1.6		
54			69.2	.5		1.6	
91	82219-12	<i>Penicillium</i> sp.	63.6		1.8		Normal.
92			60.8			1.0	
93			64.9	2.1			
184	112217	<i>Penicillium pinophilum</i> .	70.7		1.9		Pinkish, red in spots.
185			65.5			2.8	
186			65.1	2.0			
193	6520-3 ²	<i>Penicillium</i> sp.	67.5		1.9		Slightly pinkish.
194			73.0			2.5	
195				1.2			
43	10918-6	<i>Citromyces</i> sp.	66.4		1.8		Normal.
44			59.6			1.7	
45				.5			
55	10918-12	<i>Citromyces</i> sp.	67.9		2.0		Pinkish cinnamon.
56			63.5			1.6	
57				.6			
34	10918-1	<i>Gliocladium</i> sp.	62.1		1.5		Normal.
35			60.2			1.5	
36				1.1			
46	10918-5	<i>Spicaria</i> sp.	67.1		1.4		Do.
47			63.7			1.0	
10				1.0			
11	32019-7	<i>Papulospora nigra</i> .	65.4		1.7		Do.
12			63.4			1.7	
67				1.0			
68	32019-2	<i>Alternaria</i> sp.	61.9		2.0		Light gray.
69			58.7			1.7	
40				.9			
41	10918-4	<i>Trichoderma</i> sp.	65.3		1.5		Normal.
42			61.5			1.2	
9				.6			
7	3818-1	Unidentified.	69.8		1.3		Light gray.
8			59.4			1.1	
13				1.0			
14	81318-1	do.	62.8		1.8		Do.
15			63.9			1.8	
73				.4			
74	82219-2	do.	62.1		1.9		Light mouse gray.
75			59.9			1.4	
79			67.3	.5			
80	82219-5	do.	63.3		1.1		Light gray.
81			58.3			1.2	
82			62.4	1.1			
83	82219-9	do.	69.0		1.9		Do.
84			53.6			1.9	
94			66.1	1.2			
95	82219-18	do.	69.0		1.7		Mouse gray.
96			67.5			2.4	
103			71.5	1.2			
104	10918-7	do.	64.6		1.5		Deep neutral gray.
105			66.0			1.4	
116			73.2	1.6			
115	82219-23	do.	59.3		1.9		Do.
117			68.5			1.4	
	Average		65.0	1.0	1.5	1.6	

² Isolated from water.

TABLE 15.—*Deterioration of ground wood caused by 13 hymenomycetes which were isolated from wood pulp*

Sample No.	Culture No.	Organism	Per cent moisture	Per cent loss in weight after—			Physical condition of pulp
				6 months	9 months	12 months	
196	Uninoculated.	{ <i>Parillus pannoides</i> .	-----	0.5	-----	Normal.	
197			-----	(1)	-----		
198			67.3	-----	0.6		
32			-----	1.9	-----		
30	102019-1	{ <i>Parillus pannoides</i> .	65.3	-----	2.8	Pinkish buff to russet; slightly brittle.	
31	64.4		-----	3.6			
5	-----		4.2	-----			
4	82219-4		Unidentified	74.2	-----		5.6
6	-----	-----	67.0	-----	7.7	Ochraceous buff or tawny, mottled with white; slightly brittle.	
21	82219-13	do	-----	2.2	-----	Normal.	
22			69.8	-----	(1)		-----
23			66.5	-----	-----		3.4
26			-----	18.1	-----		-----
25	82219-15	do	73.4	-----	21.1	Clay color to clove brown; friable.	
24	76.1	-----	-----	26.4			
27	102019-1a	do	-----	1.5	-----	Normal.	
28	69.1		-----	2.3	-----		
29	64.4		-----	-----	2.3		
49	-----		1.0	-----	-----		
50	10918-10	do	68.7	-----	1.8	Do.	
51	56.3	-----	-----	3.6			
100	4620-2	do	75.0	27.1	-----	Cinnamon-buff to chaetura black; very friable.	
101			-----	-----	(2)		-----
102			79.8	-----	-----		49.5
106			72.9	22.2	-----		-----
107	4620-1	do	75.2	-----	33.1	Do.	
108	77.8	-----	-----	38.6			
127	61020-1	do	73.2	11.6	-----	Cinnamon-buff; very brittle.	
128			72.4	-----	18.7		-----
129			72.3	-----	-----		18.9
133			70.1	2.1	-----		-----
134	61520-1	do	68.1	-----	3.1	Normal, except maize yellow; chlamydospores on surface.	
135	66.4	-----	-----	* 2.1			
163	6920-2	do	66.7	2.3	-----	Normal.	
164			64.0	-----	2.4		-----
165			62.8	-----	-----		* 2.3
166			68.8	4.1	-----		-----
167	6320-1	do	67.7	-----	5.2	Normal color; somewhat brittle	
168	60.6	-----	-----	6.8			
172	6920-1	do	67.3	3.3	-----	Ochraceous buff or tawny, mottled white; slightly brittle.	
173			62.2	-----	5.1		-----
174			60.6	-----	-----		7.9
			-----	-----	-----		-----
Average			68.7	8.8	10.6	15.3	

¹ Contaminated.² Transplants did not grow. Results of this set not included in averages.³ This culture was lost.

The loss in weight in 6 months varied from 1 to 27.1 per cent. The average loss in 6 months was 8.8 per cent. In 9 months from 1.8 to 33.1 per cent was lost, the average being 10.6 per cent. In 12 months from 2.3 to 49.5 per cent loss occurred, the average being 15.3 per cent. (See fig. 2.)

Table 16 records the results obtained with 11 hymenomycetes isolated from wood and one isolated from water. All except one of these fungi discolor pulp to such an extent as to damage the paper made from it. Eight species made the pulp more or less brittle, and one made it so friable as to be absolutely worthless. The moisture content of the samples varied from 55.8 to 72.5 per cent, the average being 64.7 per cent. Four of the fungi died before the end of 12 months, these being the least virulent of this group of wood destroyers.

The loss in weight in 6 months varied from 1.8 to 21.5 per cent, the average loss being 10.5 per cent. In 9 months from 2.2 to 30.3

per cent was lost. The average loss was 14.4 per cent. In 12 months from 5.5 to 40.2 per cent was lost; average, 18 per cent. The four sets of tests in which the fungi died are not counted in the results.

The loss in the check cultures shown in all three tables is to be attributed to the changes brought about by sterilization and drying and to some slight loss due to handling; hence an experimental error of from ± 0.4 to ± 0.6 per cent should be allowed in all cases.

It will be observed that in some instances the loss in weight in 12 months was less than in one of the shorter periods. The following

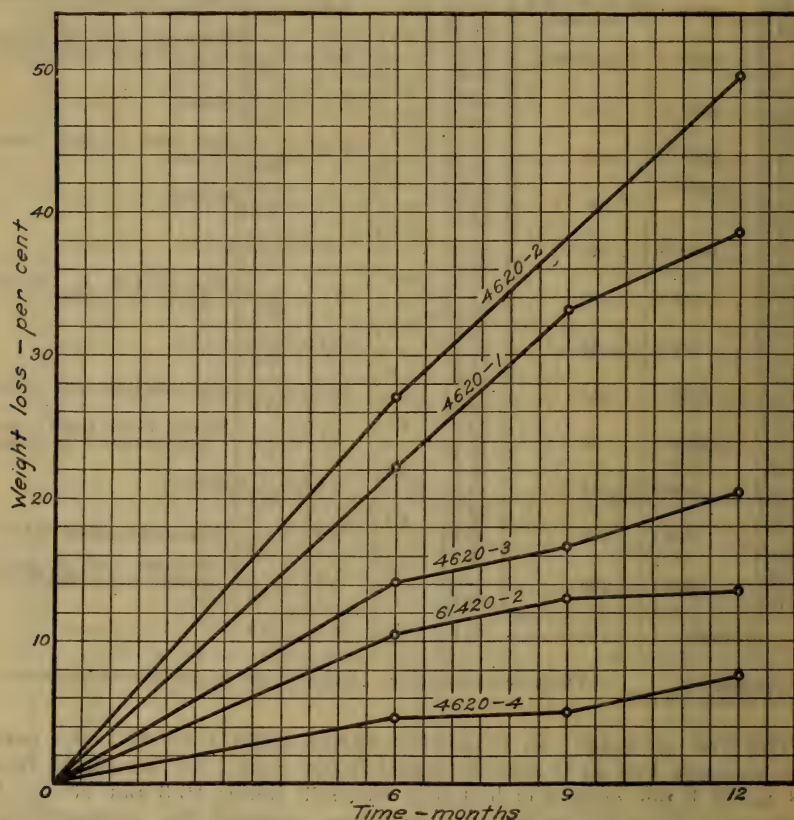


FIG. 2.—Graphs showing loss in weight of ground-wood pulp after infection in pure culture by various wood-destroying fungi

facts are offered in explanation of this apparent anomaly: Some, at least, of the tests indicate a decrease in the vitality of the organisms. Moreover, the weight of the fungous mycelium has not been taken into account; this will vary considerably, according to the nature of the fungus in question, and may amount to as much as several grams. Buromsky (8) reports a growth of 2.4 grams for *Aspergillus niger* when grown in favorable culture solutions, whereas some of the species used in the tests, especially among the hymenomycetes, produce a much more luxuriant growth of mycelium than does *Aspergillus niger*.

TABLE 16.—Deterioration of ground wood caused by 11 *hymenomycetes* isolated from wood and one from water

Sample No.	Culture No.	Organism	Per cent moisture	Per cent loss in weight after—			Physical condition of pulp
				6 mos.	9 mos.	12 mos.	
196	Uninoculated			0.5			Normal.
197				(1)			
198					0.6		
157	61420-1	{ <i>Lentinus lepi-</i> <i>deus</i>	67.6	21.5			Cinnamon to sayal brown; very friable.
158			71.7		30.3		
159			70.3			40.2	
130	61420-2	<i>Fomes roseus</i>	70.3	10.3			Cinnamon-buff to clay color; somewhat brittle.
131			67.2		12.9		
132			68.1			13.5	
139	62520-1	{ <i>Stereum sang-</i> <i>uinolentum</i>	66.4	1.8			Cinnamon.
140			62.8		2.2		
141			60.8			2.8	
142	62520-2	{ <i>Corticium ga-</i> <i>lactinum</i>	62.0	2.2			Cinnamon-buff.
143			60.4		3.3		
144			62.5			2.8	
148	8620-1	{ <i>Peniophora ta-</i> <i>bacina</i>	70.0	13.5			Cinnamon-buff; very brittle.
149			70.6		19.5		
151			57.1			22.4	
136	61420-3	Unidentified	62.8	8.7			Pinkish buff; very brittle.
137			58.9		13.9		
138			60.8			18.1	
145	62220-1 ³	do	63.7	3.2			Cinnamon-buff to clay color; slightly brittle.
146			63.1		4.2		
147			55.8			5.5	
152	61420-7	do	67.0	7.9			Cinnamon-buff; very brittle.
150			67.8		12.8		
153			58.9			16.1	
154	61420-5	do	67.6	2.0			Normal.
155			65.1		2.4		
156			61.8			2.3	
160	61420-4	do	65.6	2.8			Cinnamon-buff; slightly brittle.
161			63.9		2.6		
162			64.6			2.4	
175	4620-4	do	66.6	4.7			Clay color; slightly brittle.
176			60.9		5.0		
177			62.1			7.6	
178	4620-3	do	69.3	14.1			Cinnamon-buff; very brittle.
179			63.4		16.6		
180			72.5			20.4	
Average.....			64.7	10.5	14.4	18.0	

¹ Contaminated.² Transplants did not grow. Results of this set not included in averages.³ Isolated from river water.

Trichoderma sp. (6520-2), *Aspergillus fumigatus*, *Penicillium* sp. (6520-3), and *P. pinophilum* dissolve cellulose when planted upon cellulose agar (McBeth and Scale's formula) and kept at 28° C. In the pulp, at about 21° C., however, they produce a loss in weight of only 1.4 to 3.2 per cent, which is far below what might be expected of cellulose-dissolving organisms. Under commercial methods of storage *Trichoderma* sp. (82219-10) turns pulp bright yellow; *Penicillium pinophilum* and *P. purpurogenum* and other species of *Penicillium* produce red discolorations which vary from light pink to purple-red; *Spicaria* sp., *Alternaria* sp., and two unidentified cultures (82219-2, 82219-18) cause brown spots which would appreciably lower the quality of paper made from pulp infected by them; and eight of the unidentified molds (3818-1, 81318-1, 82219-5, 82219-9, 10918-7, 82219-23, and 82219-21) produce gray pulp.

Since the more pronounced discolorations common to the above fungi did not occur in the jar tests, one can only conclude that some factor was unfavorable to their best development in the series of

experiments reported. As in the case of molds, some of the hymenomyces have been observed to cause much more damage under normal conditions of storage than they did in pure culture tests.

Among the factors contributing to this reduced activity of the fungi in certain of the artificial cultures, both temperature and moisture doubtless play an important part. No one temperature would be the one most favorable for the maximum growth of all the 54 species tested. The temperature of 21°C ., at which the cultures were stored, would be too low for the most vigorous growth of many of them. Laboratory temperature (approximately 22 to 28°C .) appeared to be better. (See Pl. XIX, figs. 2 and 3.) The moisture requirements may also vary greatly for the different fungi. (See

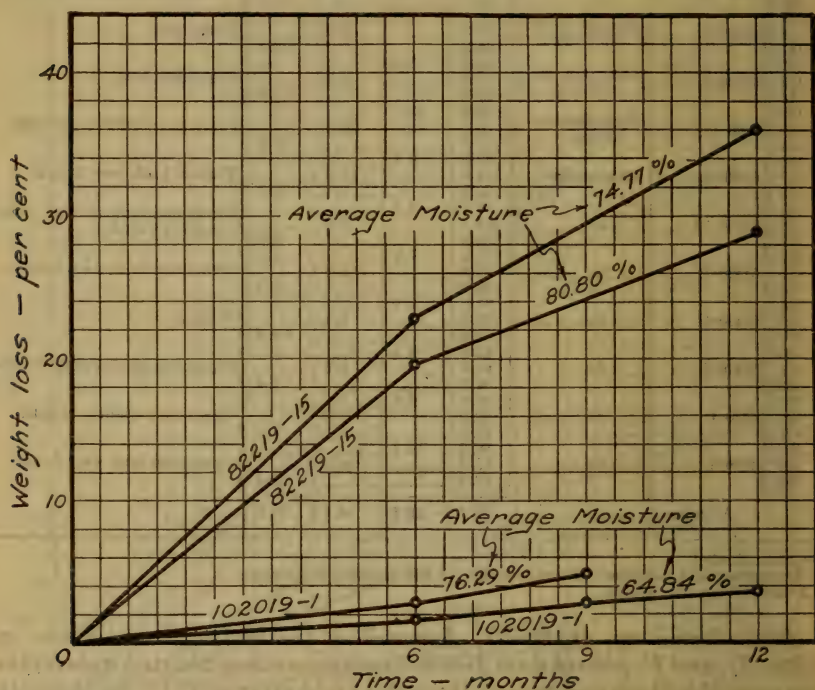


FIG. 3.—Graphs showing loss in weight of ground-wood pulp due to pure cultures of two wood-destroying fungi under two different moisture conditions.

fig. 3.) In some of the jars the pulp evidently became either too dry or too wet for the maximum growth of the fungi. (Refer to Table 14 for pronounced variations in moisture content.)

CHEMICAL PROPERTIES

It has been demonstrated that the growth of the organisms of decay in wood pulp is accompanied in most cases by a loss in weight of the pulp. From data available in the technical literature (22) it is evident that under the action of these organisms the complex wood substance is broken down into simpler compounds, some of which are water-soluble and some of which pass off as gases. With this in mind, a study was made to determine the changes in the chemi-

cal properties of some of the ground-wood pulps the physical properties of which have just been discussed. (See Tables 14, 15, and 16.) The changes that accompany the action of molds and of wood-destroying fungi appear to be different, in degree, at least, if not in kind.

EFFECT OF MOLDS

In Table 17 are presented the results of the chemical analyses of ground-wood pulps inoculated with 26 molds in pure culture and subjected to storage for periods of 6, 9, and 12 months. The loss in weight is also shown. The data in all cases are calculated on the basis of the original dry weights of the samples taken.

TABLE 17.—Chemical analyses of ground-wood pulp deteriorated by pure cultures of molds

Sample No.	Incubation period	Organism or culture No.	Original loss	Cold water soluble	Hot water soluble	Sodium hydroxide soluble	Lignin	Cellulose
	Months		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Sound pulp			0.0	0.0	1.0	10.1	29.7	60.0
9	6	3818-1	.6	.2	1.5	11.7	28.1	59.0
7	9		1.2	.8	2.1	12.9	28.2	58.4
8	12		1.0	1.8	4.4	14.4	29.0	58.0
43	6	<i>Citromyces</i> sp.	1.1	.0	1.2	14.5	28.5	57.8
45	12		1.7	1.0	3.4	14.4	29.0	57.7
52	6		0.7	1.8	2.8	14.8	29.0	60.0
53	9	<i>Penicillium purpurogenum</i>	1.6	1.0	1.9	13.7	28.5	57.4
54	12		1.5	.9	3.4	15.5	29.1	58.8
55	6		.4	1.1	2.5	14.3	29.1	57.6
56	9	<i>Citromyces</i> sp.	1.9	1.4	2.7	14.3	28.5	57.1
57	12		1.6	1.1	4.4	13.0	29.1	57.7
73	6		.3	.6	1.3	14.2	29.2	58.5
75	12	82219-2	1.4	.1	3.2	13.0	29.3	56.8
82	6	82219-9	1.2	.8	1.8	12.7	28.5	57.3
83	9		1.8	.0	1.4	12.4	27.8	58.3
84	12		1.9	.0	3.0	12.5	29.5	56.6
116	6	82219-6	1.5	.8	.0	10.9	29.0	58.2
115	10		1.9	1.5	2.1	13.0	29.1	56.8
117	12		1.3	1.5	3.1	13.9	30.1	57.5
118	6	82219-21	1.1	1.2	.3	10.6	29.0	59.2
120	12		1.0	2.0	3.2	14.6	30.1	57.2
94	6		1.1	.9	1.8	11.4	29.0	57.9
95	9	82219-18	1.6	.5	1.8	13.2	29.1	55.4
10	6	<i>Papulospora nigra</i>	1.0	.7	1.7	15.8	28.3	56.3
11	9		1.6	.7	4.1	14.9	29.0	50.0
19	6		1.7	.8	1.2	12.4	28.1	57.7
20	9	<i>Penicillium</i> sp.	1.4	.8	2.8	12.0	28.8	59.0
34	6		.6	.2	2.2	14.5	29.1	56.7
35	9		1.4	1.3	3.3	14.3	29.3	58.6
48	6	<i>Gliocladium</i> sp.	1.0	.0	.3	12.7	28.4	59.7
46	9		1.4	.8	2.9	13.5	29.7	56.0
91	6		.4	1.6	2.7	13.3	28.7	56.6
92	9	<i>Spicaria</i> sp.	1.8	1.5	3.3	16.5	28.5	56.1
103	6		1.2	1.5	1.1	11.1	28.7	57.0
104	10		1.4	3.0	3.8	12.7	29.0	57.4
13	6	81318-1	.9	.2	2.0	12.9	28.1	57.3
16	6		.4	.5	1.4	13.5	28.0	58.0
37	6		.9	.5	2.1	15.5	29.1	57.1
40	6	<i>Penicillium</i> sp.	.8	.7	1.8	15.1	29.2	57.5
65	6		.3	.8	1.8	13.3	28.9	58.0
67	6		.9	.6	1.6	13.6	28.8	57.5
70	6	82219-1	.1	1.1	1.8	13.3	28.9	58.5
85	6		.4	1.6	2.1	14.0	28.4	57.6
88	6		.9	1.5	2.7	13.5	28.4	56.7
112	6	<i>Mucor</i> sp.	1.2	1.4	1.1	11.4	29.0	58.6
122	6		1.6	.9	.0	10.4	29.4	58.5

A comparison of these data with the data for sound pulp shown in the same table indicates that only small changes were produced. The loss in weight in no case exceeded 2 per cent, and the increase in solubility in cold water, hot water, and sodium hydroxide did not exceed 3 per cent, 3.5 per cent, and 6.5 per cent, respectively. In only one case was the loss in cellulose greater than 4 per cent. The slow rate of deterioration is evident from the typical set of curves, Figure 4. The 10 per cent loss in the case of *Papulospora nigra* is not excessive nor indicative of far-reaching decomposition; it approaches

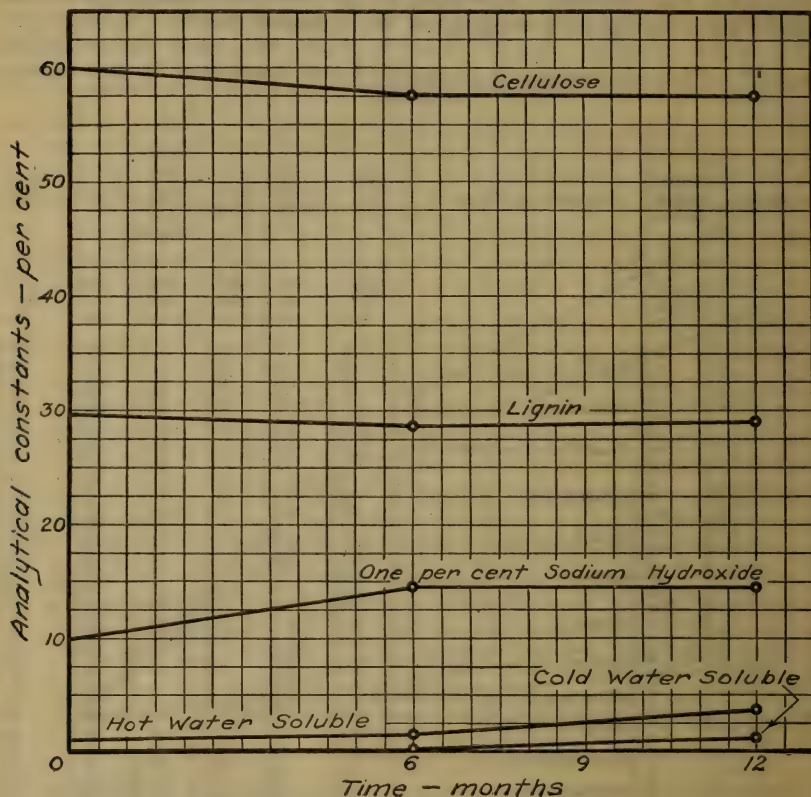


FIG. 4.—Graphs showing analytical constants of ground-wood pulp infected with a mold culture, No. 10918-6

in value, however, some of the losses due to some wood destroyers, which is to be expected since *Papulospora nigra* is closely related to the hymenomycetes.

EFFECT OF WOOD-DESTROYING FUNGI

That the action of wood-destroying fungi on the chemical components of ground-wood pulp is more vigorous than that of molds, will be seen from a study of Table 18 in which are set forth the chemical data for one sound ground-wood pulp, and ground-wood pulps inoculated with 21 of these fungi.

TABLE 18.—Chemical analyses of ground-wood pulp deteriorated by pure cultures of hymenomycetes

Sample No.	Incubation period	Organism or culture No.	Original loss	Cold water soluble	Hot water soluble	Sodium hydroxide soluble	Lignin	Cellulose
	Months		Per cent 0.0	Per cent 0.0	Per cent 1.0	Per cent 10.1	Per cent 29.7	Per cent 60.0
Sound pulp								
26	6		18.1	4.9	9.0	37.8	28.8	35.5
25	9	82219-15	21.1	5.9	10.5	37.6	28.4	33.4
24	12		26.3	6.4	11.3	38.3	28.8	27.8
100	6		27.1	8.0	13.0	40.0	27.7	26.8
102	12	4620-2	49.4	7.3	11.0	33.4	26.6	10.8
106	6		22.2	9.5	13.7	40.7	30.7	29.0
107	10	4620-1	33.1	11.1	15.2	41.6	28.8	18.2
108	12		38.6	9.1	13.0	38.0	28.5	16.9
127	6		11.5	3.9	7.2	30.9	29.1	40.6
128	9	61020-1	18.9	6.1	8.9	32.5	29.5	36.9
130	6		10.3	2.8	5.7	29.6	30.6	44.2
131	9	<i>Fomes roseus</i>	12.9	3.2	5.1	29.2	30.7	44.1
148	6		13.5	4.8	8.9	34.9	27.7	40.4
149	9	<i>Peniophora tabacina</i>	19.4	4.9	7.9	37.2	32.0	35.1
178	6		14.1	6.0	9.8	33.0	29.3	38.0
179	9	4620-3	16.5	6.5	10.2	36.3	29.0	37.3
152	6		7.9	4.2	7.0	25.5	29.0	48.8
150	9	61420-7	12.8	5.3	8.5	40.2	34.6	38.0
157	6		21.5	7.5	11.8	41.0	28.8	32.0
158	9	<i>Lentinus lepideus</i>	30.3	9.6	15.7	40.5	28.6	24.2
5	6		4.1	2.3	5.4	21.0	26.8	56.0
4	9	82219-4	5.6	2.1	6.0	19.7	27.3	54.7
6	12		7.6	3.6	7.5	21.6	26.6	53.4
27	6		1.4	2.3	4.6	14.1	29.4	56.7
28	9	102019-1a	2.3	1.9	3.5	13.8	29.1	58.0
32	6		1.9	0.0	1.6	13.6	28.7	55.6
30	9	<i>Paxillus panuoides</i>	2.8	0.6	5.0	14.4	28.4	55.8
31	12		3.5	1.3	4.5	17.8	27.7	55.9
49	6		1.0	0.0	0.5	13.0	28.7	57.6
50	9	10918-10	1.7	0.1	2.4	12.0	29.6	57.0
133	6		2.0	1.5	3.2	13.9	29.4	57.4
136	6	61420-3	8.6	5.0	7.8	30.6	29.3	45.1
137	9		13.9	5.9	10.0	37.2	29.2	38.3
142	6	<i>Corticium galactinum</i>	2.1	1.7	2.9	15.8	28.4	57.2
145	6		3.1	1.1	2.3	14.5	28.4	57.7
146	9	62220-1	4.1	2.2	3.9	19.5	32.0	56.0
160	6		2.7	1.7	3.0	17.1	28.9	55.8
172	6	61420-4	3.3	2.3	3.6	15.8	28.8	56.4
173	9		5.1	2.7	5.5	22.0	27.2	53.8
175	6	6920-1	4.7	3.2	5.7	20.7	27.4	54.8
176	9		5.0	2.7	4.7	20.8	26.9	54.6
181	6	62020-1	0.8	1.9	2.1	14.2	29.1	50.5

The large losses in weight, which with one fungus reached 27.1 per cent in six months and 49.5 per cent in 12 months, were reflected in the chemical data. The solubility in cold and hot water and in sodium hydroxide in practically all cases increased very substantially, and reached maxima of 11.1 per cent, 14.7 per cent, and 40 per cent, respectively. The decreases in cellulose content were also very marked. The reduction in one case was 10.9 per cent.

In striking contrast with the other chemical data is the fact that the lignin content remained practically constant and independent of decay. Its variations from the value of sound pulp were not much greater than the experimental error. The action of the fungi investigated was, therefore, apparently selective in that it did not involve to any appreciable extent of decomposition of lignin. Unfortunately it was the cellulose, which from the paper-making standpoint is the most important part of the wood, which suffered the greatest deterioration.

Fomes roseus, *Peniophora tabacina*, and cultures 82219-15, 4620-2, 4620-1, 61020-1, and 4620-3, acted rapidly during the first six months of storage, as is indicated by the great changes recorded. After six months the rate of change decreased very noticeably. This is evident from the curves shown in Figure 5, which are typical of these cultures. The decrease in rate of deterioration may be accounted for in one or all of the following three ways:

1. There may be a decrease in the vitality of the organism, due perhaps to autointoxication.

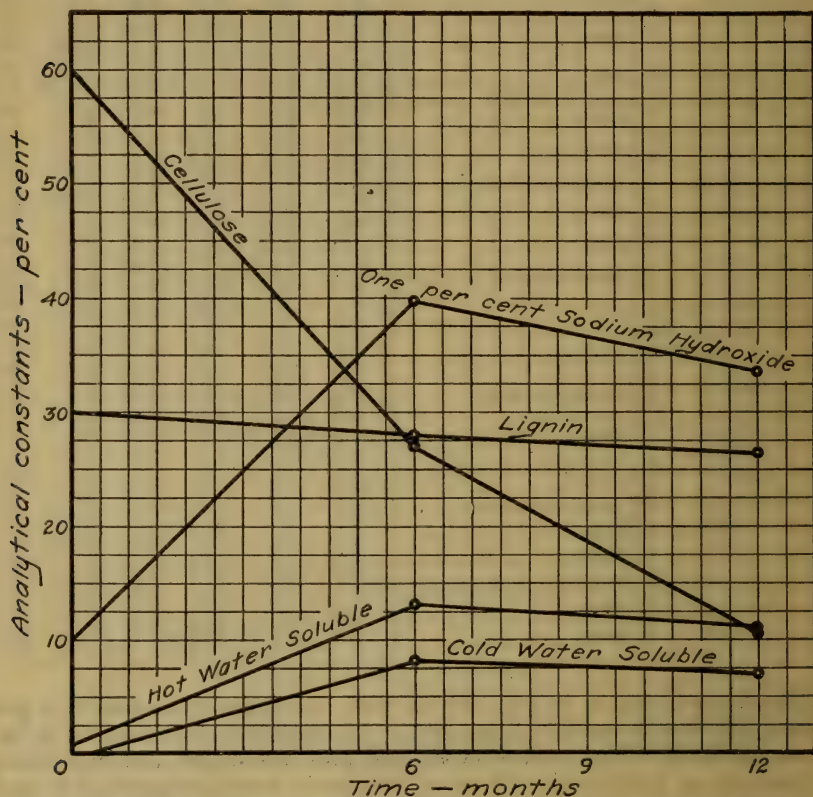


FIG. 5.—Graphs showing analytical constants of ground-wood pulp infected with a hymenomycete culture, N. 4620-2

2. The cellulose which remains after a certain period may not be available to the fungus. Assuming that the fungus uses the more accessible cellulose, leaving the lignin, the remaining cellulose in the ligno-cellulose complex may be more or less encrusted with pure lignin and so protected, to a certain extent, against further breaking down.

3. The cellulose in the cell walls of the fungus, although somewhat different from ordinary cellulose, may cause a slight increase in the cellulose determination.

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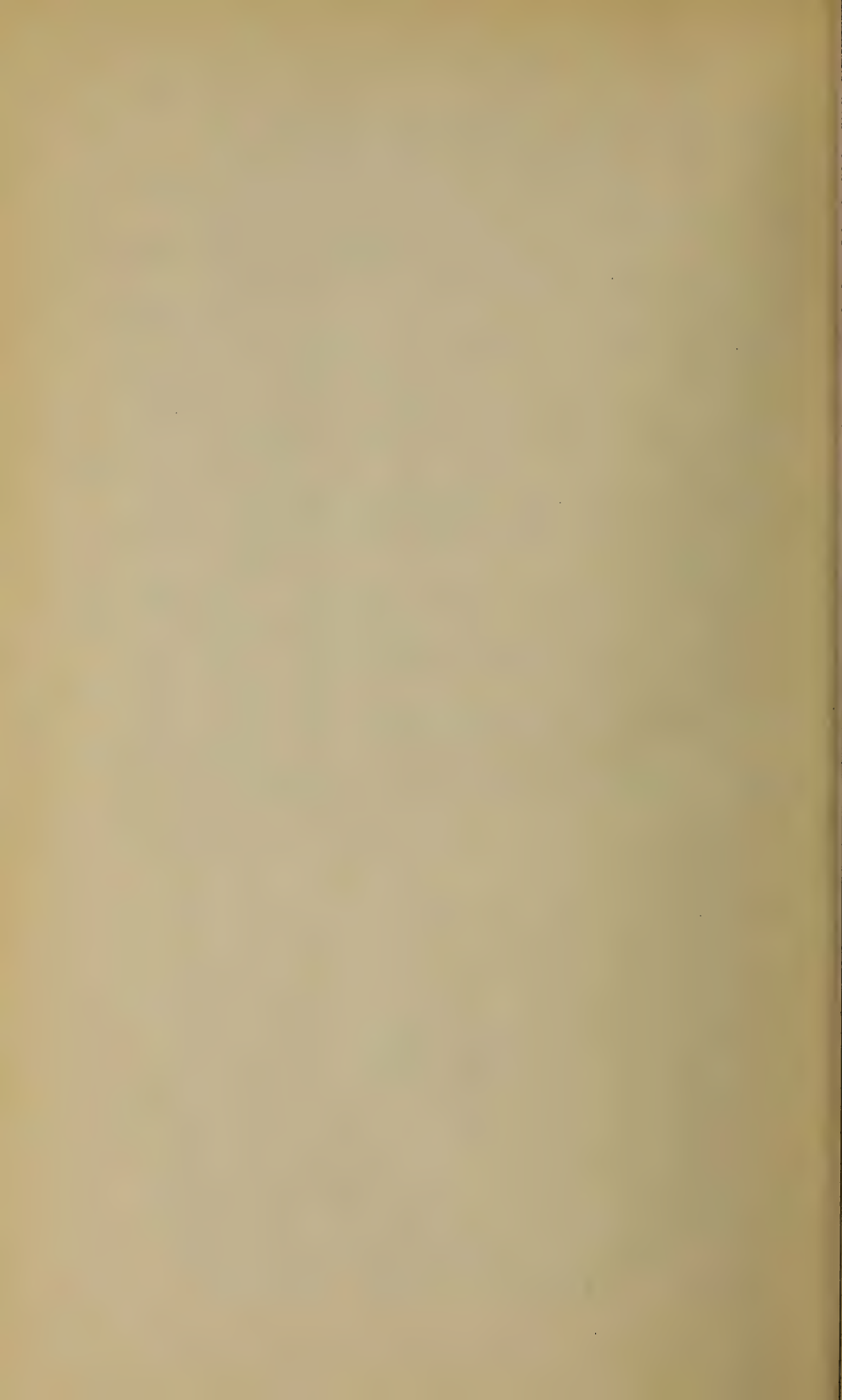
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